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THE GLASGOW TEXT BOOKS OF CIVIL ENGINEERING. EDITED BY G. MONCUR, B.SC. M.I.C.E., M.AM.SOC.C.E. *Professor of Civil Engineering in the Royal Technical College. Glasgow.*

DOCK AND LOCK MACHINERY

UNIV. OF CALIFORNIA

THE GLASGOW TEXT BOOKS.
EDITED BY G. MONCUR.

DOCK AND LOCK MACHINERY

A TECHNICAL MANUAL

BY

W. HENRY HUNTER
M.INST.C.E., M.AM.SOC.C.E.

With Ninety-seven Illustrations

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PREFACE

It is a truism, perhaps a platitude, to assert that the first duty of one who essays the art of public speaking, and thereby invites others to yield attention to his words, is to interest his audience; as apart from such interest the speaker is not likely either to engage the mind or to convince the understanding of a single member of that audience.

It is equally true that the initial duty of one who undertakes any burden of authorship, even in so unpretending a manner as in this monograph, and who thus appeals for the suffrages of a particular (and critical) class of readers, is to make his work readable, is to make it of such sort that it will not only accord with the dictum of Aristotle that "any written composition ought to be easily read," but that it may be perused without boredom or exhaustion of interest.

One who writes and hopes that others will read has a more difficult position to maintain than one who speaks and invites others to hear. The latter can, and if he has in him a vein of humour or a grain of sense does, illumine a dull theme and give colour to a grey monochrome by the introduction of narrative (even though the narrative may not be very relevant), or of allusion. Such aid is forbidden to a technical writer of the present day by an inane though potent authority entitled Convention.

Convention seeks to drag down to the level of its own inanity all the features and departments of modern life and literature, including even such literature as appears in the guise of Engineering publications.

This was not always the case. Some of the treatises and reports which were issued from the studies or the offices of the fathers of modern Engineering were full of interest and even of romance; while in particular cases the quaintness of their restrained humour was irresistible.

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But these good old days are gone, and now Conventionalism holds sway over the minds of students and of men, and frowns on any attempt to make technical treatises readable whatever the subjects of these treatises may be.

How then is it possible to render a manual on a theme so prosaic and one confined within limits so strait as that of "Dock and Lock Machinery" interesting so far as to make it readable; to make it such that it may be perused if not with pleasure, at least without aversion? This seems to pass the wit of man; at any rate, the wit of the man who has made the effort which is comprised in the following chapters; and who feels that the best things which can be claimed for this small work are (1) that sincere endeavour has been made in it to ensure that the materials on which it is based should be obtained from original sources, and that in this way accuracy of description as well as of historical statement should be attained, and (2) that where opinions have been expressed in its pages the opinions have been "broad based," not only on precedent, but on lengthened personal experience, for which reasons they may perhaps be accepted tentatively by those who, in some measure of toil and travail, are acquiring experience for themselves.

With regard to the materials referred to in the foregoing paragraph, I have pleasure in acknowledging here my indebtedness to the Directors of Messrs. Sir W. G. Armstrong, Whitworth and Company, Ltd., for the courtesy which led them even in the midst of the pressure of their great national work, to lend to me, through Mr. C. O. Ridley, and for the purposes of this Manual, the unique and historical series of working drawings of the Dock and Lock Machinery in use in so many parts of the world, in the manufacture of which the Elswick Works have been engaged since 1850; to Gen. George W. Goethals, U.S.A. (formerly Chief Engineer to the Panama Canal and now Governor of the Canal Zone), for working drawings and other information relating to the lock machinery on the Panama Canal in Central America; to Mr. John A. Bensel, M.Am.Soc.C.E. (Engineer and Surveyor to the State of New York, U.S.A., and Chief Engineer to the New Erie Canal from 1911 to 1914), for similar particulars in respect of the locks on the Erie system of Barge canals; to the Chester Hydraulic Engineering Company, Ltd., of Chester, for drawings of the gate machines in the lock at the King George Dock in Hull; to the Editors of "Engineering" and to others who have furnished me with, or have permitted me to use, information for the same purposes.

W. HENRY HUNTER.

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Manchester.

EDITOR'S NOTE

The author had practically completed the subject matter of this volume when he was overtaken by an illness which he was unable to throw off and his regretted death took place in February, 1917. His career had been a long and strenuous one, concerned in the conception and carrying out of public works of magnitude, notably the Manchester Ship Canal, of which he was the consulting engineer, and he was also a Member of the Board of Consulting Engineers on the Panama Canal. His professional work was chiefly directed to the Improvement of Rivers and Estuaries and to the Design and Construction of Docks and Canals. In these pages on "Dock and Lock Machinery," he has put before his brother engineers the fruits of a prolonged experience, and has traced the evolution of the various types of machines to their modern forms.

On the author's death Mr. J. A. Orrell, A.M.Inst.C.E., Manchester, formerly his chief assistant, kindly consented to do what little remained to complete the volume. The text has been little altered, but some additional matter has been included, comprising a description of the mode of operating the floating caissons at Rosyth, for which the Editor is indebted to Mr. Adam Hunter, M.Inst.C.E., of Sir Wm. Arrol & Co., Ltd., who supplied the necessary information.

The publication of the book has been delayed from circumstances arising out of the war, but it is hoped that it will be none the less useful, more especially as it contains in a collected form information which is otherwise scattered and not easily accessible.

G. M.

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DOCK AND LOCK MACHINERY

CHAPTER I

INTRODUCTORY AND HISTORICAL

EVOLUTION AND EFFICIENCY IN THE ENGINEERING WORLD

For the series of Engineering manuals of which this work forms part, it may be claimed, and with justice, that the series has a place which is peculiarly its own, not only in contemporaneous literature but in contemporaneous history, a place to which attention may be fittingly directed, and for which room may with propriety be demanded. Should question be raised as to the basis of this claim, which is hardly likely, the answer will be that the publication of the several manuals and the development of a series of works of so high a degree of specialization, are at once the outcome of a slow but irresistible movement which has been in progress in the engineering world during the last half-century; and are also a testimony to the manner in which the men of that world have accommodated themselves to the change. Further, these men have perhaps instinctively endeavoured to adapt themselves to the results of the evolutionary movements in their environment, which have been produced by external causes of the nature described by lawyers as *force majeure,* that is to say, by forces which are too powerful for human resistance to withstand and which are often too obscure for human perspicacity to disentangle; as although the mechanical elements in the forces may be reduced to mass and velocity, and may be expressed by a function of these elements, there are other factors to consider which go far beyond questions of mechanics or matters of measurement.

One example of the effect of the evolution* which has occurred and of the change which has taken place will suffice for the present purpose. In the engineering economy the "all round man" who once held the field has almost disappeared, and the specialist has taken his place. There is much that is to be regretted in the change. The younger men amongst the English-speaking engineers of the day may not be able to appreciate the solidity of the basis upon which the regret is founded, or to find reasons therefore within the limits of their own horizon. But it was an accomplished scholar and a well-known guide of youth † who always insisted that "we are none of us infallible, not even the youngest of us," and the minds of these younger men may find a corrective for any lack of appreciation or for shortness of vision, in the history of their country, of their profession, and of the works of their predecessors. The older men know well what the "all round man" did for the world, and what the modern engineer owes to him. But this useful personality has almost disappeared, and soon will have vanished from the earth; just as the old-time millwright (whose activities led him from the lathe or vice to the carpenter's bench and from thence to the blacksmith's anvil) has vanished, vanished so completely that his ways, his works, his existence even, have become a mere tradition of an outworn past. Yet it is not too much to say in the words of Samuel Smiles, the distinguished author of the "Lives of the Engineers," that "men trained in millwrights' shops such as Brindley, Meikle, Rennie and Fairbairn were borne up by the force of their practical skill and constructive genius into the highest ranks of skilled and scientific engineering." ‡

Increase of human knowledge has the effect of an extension of the horizon, that is to say, an expansion of the area covered by human experience. It is but necessary to carry the expansion to a sufficient degree to render it impossible for even the mightiest intellect to cover the whole area, hence the necessity for the specialization by which all the diverging branches of science and of art are already directed and controlled, and which must increase in intensity as the expansion proceeds.

---

* The word "evolution" was described in the ninth edition of the "Encyclopædia Brittanica," by the late Rt. Hon. Thomas Henry Huxley, P.C. (better known to his contemporaries as Professor Huxley), as being "a general name for the history of the steps by which any living being has acquired the morphological and physiological characters which distinguish it." For "any living being" substitute "the economic condition," and for "morphological and physiological" substitute "mechanical and sociological," and Professor Huxley's description will serve for the sense in which the word is used in these pages.

† The late Mark Pattison, one time Rector of Lincoln College, Oxford.

‡ "The Lives of the Engineers," Vol. I, p. 311.

The reasons for the change in engineering circles and the movements through which the change has been brought about are fraught with interest, not only for every engineer, but for every thinking man, but this is not the place for their detailed consideration. Briefly, the first of the reasons may be said to be the increased necessity for efficiency at the present time, due to the increase of the intensity of the competition between men and nations; and the second, the unparalleled growth in knowledge which has taken place during the period with which we are concerning ourselves here. These reasons are indubitable, they are on the surface, and are therefore obvious; but beneath them is an outstanding fact which has affected every phase of human life.

The outstanding fact is that it is almost beyond question that the population of the globe doubled in the course of the nineteenth century. In round figures, at the beginning of that century the world's population was somewhere about eight hundred millions of souls, at its close the population was at least sixteen hundred millions.

In that fact lies the true inwardness of much of the unrest of the present day. Out of that fact has grown the exigency of the demand, real though not wholly articulate, that the resources of all the earth shall be made available for the service of all the earth's inhabitants; and out of it also has arisen the requirements for increased efficiency on the part of each and every man upon whom any part of the work required for the provision of other men's needs has devolved.

Efficiency means specialization, both in design and in manufacture, and has become all the more necessary because the pressure due to increase of population in various lands (which means increase in the number of mouths to be filled) has been felt by nations in the East and in the West, and (as already hinted at) has had the effect of driving many of these nations into the arena as producers and competitors, who in past days were content to be spectators and purchasers.

Modern conditions require and will increasingly require that every man, and more especially every engineer, shall take his place and play his part in a comprehensive scheme, first, indeed, for his own benefit and for that of those immediately dependent upon him, and then for the benefit of his people; that is to say, that he must become a specialist in the sense that he must become specially skilled in some branch of his work, and if in any particular case this vital necessity serves to destroy the individuality of a particular man, the reason is, and can only be, that the individuality is such that it will not be worth preserving, and that the man will become what he is fitted for, a part of a huge machine, and probably will thus secure for himself a quiet life and a fairly comfortable existence.

The pressure due to the abnormal and unprecedented increase in the population of the world, has *inter alia* brought about during the last half-century a most extraordinary increase in the means of communication, both for persons and for goods, between all parts of the world, and more particularly during the latter half of that period.

The oceans and the seas are the highways of the world, and, as might be expected, it is on these highways that the great development has taken place; a development which has made for the benefit of humanity and which has unequivocally confirmed the dictum of the late Prince Consort, the husband of H.M. Queen Victoria and the grandfather of King George V, that "seas unite nations, they do not divide them."

The statistics which enshrine the data through which exact account can be made of the rate and the manner of the growth of the volume of the world's seaborne traffic during the lifetime of men who are as yet little more than of middle age, have a special interest of their own, and are sufficiently sensational to compel attention; but it is not necessary to find place for any epitome of these figures here, as the points with which we are concerned are rather those which relate to the increase in the dimensions of the vessels in which the trade is carried, than those which relate to the increment of the trade itself. It may be hoped, therefore, that an understanding of the course of augmentation in the length, the beam, the draught, and the power of vessels—whether intended for warlike or for peaceful purposes—which has been steadily pursued by all maritime peoples for some time past will enable the student to follow the cognate course by which works for the shelter and the accommodation of the ships have grown to their present dimensions and through which the design and the construction of *Dock and Lock Machinery* have passed out of the hands of the ancient all-round man into those of the modern specialist.

To aid this understanding two incidents in the experience of one man which occurred within a period of twenty years of his professional life may be narrated at the close of this chapter. It is possible that the narrative will furnish a more graphic record of the phenomenal growth in the size of steamships than could be conveyed by bald statistics, and as a consequence of such growth of the advance in the size of the locks which were and are regarded as necessary for the accommodation of steamships.

In the year 1887, for the purposes of the design of the works of the Manchester Ship Canal, the drawings for which were then in course of preparation, a search was made through the lists of all the steamships which were afloat at that time; and in addition particulars were obtained of vessels which were either in course of construction by shipbuilders or were contemplated by shipowners. The object of the enquiry was to determine the sizes of the locks which were to form the entrance to the great docks, the construction of which was then contemplated in Manchester, as well as those of the locks in the upper part of the waterway, through which access to the docks was to be obtained. The enquiry was one of more than ordinary importance; it was conducted with care, pains were taken to collect information, and the results were regarded as reliable. As the outcome of the investigation the dimensions of the larger lock in each pair of locks—i.e. those which were to form the entrance to the docks, and those which were to be constructed in the access thereto—were fixed at 600 feet for the length between the centres of the heel posts of the gates, and 65 feet for the width between the side walls, the minimum depth on the sills being 28 feet. These figures were considered and approved by the authorities of the Canal Company, to whom it was demonstrated that at that time there was only one steamer afloat which could not be passed through an entrance of such dimensions. That vessel (the s.s. "City of Rome," of the Inman Line), although only 586 feet between perpendiculars, was of such remarkable design that she would have required a length of 627 feet between centres of gates to allow her to pass through a lock, and as she was described by her builders and owners as an experiment (unkindly and ungentle critics employed terms of description which were perhaps more picturesque and were certainly more forcible), and as it was ultimately admitted that the experiment was unsuccessful, it was considered unnecessary to take the "City of Rome" into account, and the dimensions named were adopted and the locks were built accordingly.

In the year 1905 a similar problem presented itself in connection with another and greater waterway in a distant part of the earth—the Panama Canal—and the questions relating thereto and to the locks which might possibly form the entrances to that waterway from the two oceans which the Isthmian Canal was to connect, were referred to and were discussed by an International Board of Consulting Engineers. Of the International Board it is sufficient to say that it had been appointed by President Roosevelt for the purpose of preparing projects for the construction of the Trans-Isthmian Canal, and that it included men who had had personal part in the construction or in the development of all the ship canals in the world. The members of the Board met in Washington (D.C.), proceeded in due course to the Isthmus of Panama, and after detailed investigation of many other points, obtained exhaustive particulars relating to vessels then navigating the seas, or on the stocks in shipbuilding yards, or in contemplation by shipowners in all parts of the world. They finally arrived at the decision that it was necessary that these entrance locks should be constructed with a "usable length" of 1000 feet (equal to a length between heel posts of 1070 feet), a width of 100 feet, and a minimum depth of 40 feet on the sills. When these figures were submitted to the American Navy Board—which corresponds with the Admiralty in the United Kingdom—that Board requested that the width should be increased to 110 feet and the depth increased to 42 feet, which depth was later on increased to 45 feet; and the locks were constructed with these dimensions.

The capacities represented by multiplying together the three dimensions in each of the cases described, will furnish a common measure by which the locks of 1887 and those of 1905 can be compared. The capacity of the larger of the two entrance locks to the Manchester Docks, measured below the water-line, is 1,092,000 cubic feet, while the capacity of each of the entrance locks to the Panama Canal, when similarly calculated, is 5,296,500 cubic feet, or an increase of nearly 500 per cent. Figures of 1,000,000 cubic feet in the one case and of 5,000,000 in the other, are not difficult to remember; the comparison between the two will not tax the mathematical powers of either the oldest or the youngest amongst us, and both alike seem to show that although there may be a measure of truth in the word of the wisdom of the ancients, which was written so long ago, that "the world hath lost its youth, and the times begin to wax old," the senile decay has not affected the growth of oversea shipping or the development of engineering works.

THINGS INCLUDED AND EXCLUDED: AND A LINE OF HISTORIC GUIDANCE

It goes without saying that specialization in any field of human activity must lead to individual limitation, limitation in the field as well as in the scope of a worker therein. It should, therefore, be observed that in these pages the term or phrase "*Dock and Lock Machinery*" will be used in a strictly limited sense; so much so that the term is to be understood as relating to and descriptive of the mechanical devices of one sort or another which have been and are being provided for the purpose of facilitating the transport of floating craft of any type or size from one basin, or pond, or sheet of more or less still water, to another; the basins or ponds being, in the majority of instances, understood to be confined wholly or in part by means of artificial works, maintained by gates and controlled by sluices, or by other means by which impounded waters may be caused to pass at will, under the influence of gravity, from a higher level to a lower.

The machinery with which the gates should be equipped and by which they are opened or closed as may be desired, the sluices and other expedients by which the levels of the impounded waters may be controlled, together with the gear by which the controlling appliances are operated, and the means by which the floating craft are moved inward or outward, onward or backward, are all to be included under the head of Dock Machinery, even when used in the most restricted sense, and with the most complete regard to the limitations already referred to. But the gates themselves, whether built of timber, of iron, or of steel, are considered as integral parts of the structure of the entrance or of the lock. Questions, therefore, which relate to gate design and construction, and the questions collateral thereto, will be excluded from the present discussion. Amongst these collateral questions is a series which has emerged from experiences derived from works of repair and of reconstruction which have followed upon the many cases of injury to entrance gates, caused by the movements of passing craft during the last half-century. These questions relate to the provision or otherwise of preventive appliances, by means of which it is hoped that disaster may be averted and damage reduced to a minimum when, owing to untoward circumstances, vessels of any sort come into collision with the gates while being passed through a dock entrance. Various types of protective works have been evolved, some of them being of extreme simplicity and other of a high degree of complexity. None of them have been put to anything like serious test, and as there seems to be a more excellent way, a way by which the damage can be avoided altogether, reference to the protective works will also be excluded from these pages, and the better way only considered in detail, as *inter alia* it does involve the provision of suitable machinery.

It will be noted that all the classes of dock machinery to which reference has been made, relate only to the entrances to closed docks, by which is meant docks which are not open to the inflow and reflow of the tide, such as those at Manchester and at Bristol; or only partially open, such as some of the docks on the Thames and on the Mersey. These may be contrasted with docks like those on the Clyde and at Southampton, into and out of which such tide as there is flows without interruption.

The classes of machinery which are employed for the working of the entrances to the closed or partially closed types of docks and basins will be described and discussed in the following pages, and no other classes; but it should be understood that in considering these subjects no difference can be made and no distinction can be drawn between entrances to a closed dock and a lock proper, as the two methods of construction are for all practical purposes identical in principle and in operation. The usual form which the difference between the two takes is that a closed dock on the seaboard, if not furnished with true locks for the passage of traffic into and out of the confines of the dock, is sometimes approached through a tidal basin with entrance gates at the outer (or seaward) end of the basin, and at the outer end of the dock. In this tidal basin, any number of vessels arriving on the flood tide (up to the limit of the capacity of the basin) are berthed until they can all be raised together—or in other words locked up to the level of the water in the dock proper, so that the tidal basin with its terminal entrances forms a system which is, in fact, only a lock of enlarged capacity.

Again, there is the case of an entrance to a partially enclosed dock, the level of the water in which is maintained at a height which, while considerably above the level of low water of neap tides, is below the level of high water of the same tides (so that on every day in the year, except during the periods of lowest neap tides, some quantity of tidal water must flow into and out of the dock), and where the traffic is worked in and out during the period when the gates stand open—i.e. the period during the rise of the tide from the level of impounded water to that of high water and the period of fall from high water to impounded level again. In this case also consideration will show that there is still no difference in principle or in practice. The entrance to the partially closed dock is, in fact, represented by a lock of which the upper portion has been permanently removed and the lower length of its equipment of gates, sluices, and machinery, left in *statu quo.*

The primitive docks which were constructed in Great Britain for the accommodation of the shipping of the realm of England and of foreign powers trading therewith, were mainly, if not altogether, of the open type. The Howland Dock, which is said to have been built in 1660 at Rotherhithe, on the southerly side of the Thames (and on a site which is now absorbed in the Greenland Basin of the Surrey Commercial Dock system), was of this type, and was probably the first, or one of the first, of the British docks; while the Old Dock in Liverpool, on the Mersey, which was built in 1708 or 1709, was certainly of the closed type. These docks were the pioneers of the great array of the docks and basins of our own times, but of the dimensions of their entrances or of the details of their machinery no certain information remains. The matters relating to them are matters which more concern antiquarians and archæologists rather than up-to-date engineers of the twentieth century.

Nevertheless, a line of historic guidance should have a mnemonic value for the engineer, and such a line may, for want of a better, be found in one item in the history of the growth of inland waterways. The item relates to the design and the construction of the locks, and more particularly to the machinery with which these locks were equipped. The traffic, through these waterways, although of comparatively insignificant weight and value at the outset, grew and expanded into a capacity upon which even now we look back with astonishment, and is of almost immeasurable importance to the present generation, seeing that in and through that traffic the foundations of British commercial developments were laid, and the way made for the institution and the growth of the British Imperial Dominion.

Neither edifice nor statue is to be found in which the memory of the inventor of the device which has been so long known as a lock, has been perpetuated; so that in fact no one knows who that great benefactor of his species was. The honour has been claimed for Leonardo da Vinci the Italian, the greatest all-round man in history—painter, sculptor, musician, natural philosopher, chemist,* mathematician, and engineer, all in one, and *mirabile dictu*, excellent in all; but the claim is far from having found general acceptance. It is certain that towards the end of the fifteenth century Leonardo carried out a scheme of river improvement and canal construction for the Duke of Milan, in which locks were included and usefully employed. But a claim of anticipation of the invention has been advanced on behalf of others, particularly on behalf of certain Dutch engineers, who "unknelled and unknown" were lost in the crowd long ago, and so thoroughly lost that no reliable evidence of their existence or of their work seems to remain, upon which a sound judgment can be based.

The manner in which lock dimensions have grown and increased in recent times has already been referred to in these pages; but it will now be necessary to go back further—not, indeed, to medieval ages—but to days much nearer to our own, the days in which the great founders of the modern art of civil engineering began their construction of the works for the convenient transit of men and things from one part of Great Britain to another; works in which these venerable builders laid not only the foundations of the engineering profession, but those of the British Empire. They knew but little of the real value of their work, they never dreamed of the future results of their efforts, but they did what their hands found to do, and they did it with their might; and so they left behind them an example which, when followed (so far as things material go), still leads the way towards such success in life as is worth having.

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* In 1915 the German Press ascribed the dubious honour of another invention to Leonardo, namely that of the employment in war of asphyxiating gases for stupefying and suffocating an enemy. In support of their ascription the "Frankfurter Zeitung" asserted that in one of the eleven Leonardo MSS. which were removed by the French from the "Bibliotheca Ambrosiana" in 1796 an entry, of which the following is a translation, is contained. "By means of catapults, powdered quicklime, arsenic, and verdigris may be thrown on hostile ships: whoever inhales the same must die. But take care that the wind is not against you. To guard against mishap, the best protection is to cover the mouth with a dampened cloth. The powder may also be thrown in paper packets."

THE COURSE OF THE DEVELOPMENT

In the navigations which these pioneers of the Empire formed and the canals which they constructed, at the beginning of the eighteenth century, the "narrow boat" furnished the gauge by which the dimensions of most of the entrances and of the locks were determined. The beam of the narrow boats which were in use upon the majority of the disconnected navigations in England in the early part of the eighteenth century was about 6 feet; in accord with which the locks proposed by Brindley, in 1765, for the Trent and Mersey Canal were to be constructed for boats which were to be 70 feet long, 6 feet wide, and which, with a draught of 2 feet 6 inches, were to carry in each case a load of 20 tons and were to cost £30 apiece. Comparatively few, even of the shipping people in the United Kingdom, are aware of the volume of the traffic which is still borne in narrow boats on the inland waters of the realm; and the number is still less of those who either know or remember how largely the development of the resources of Great Britain originated in, and was founded upon, the cheap and convenient means of transport which was provided by the narrow boat traffic. Further, the barges on the English waterways were the precursors, though not the progenitors, of the gigantic craft which in normal times of international amity convey such vast quantities of produce and goods along the great arterial drains, from the inland countries, states, and districts, to the seaboard, in Europe and in America. Of these arterial drains, the Rhine with

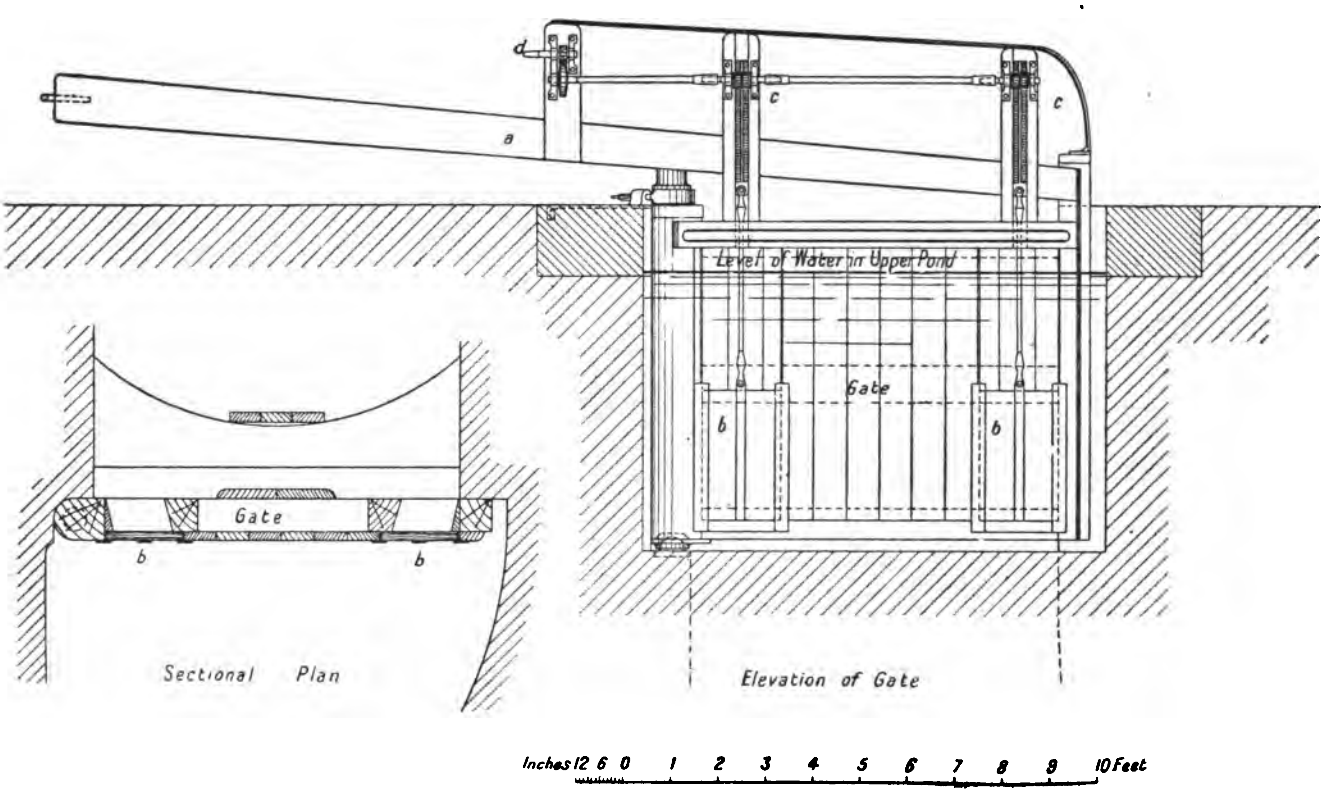
d
a
c
c
Level of Water in Upper Pond
Gate
b
b
Gate
b
b
Sectional Plan
Elevation of Gate
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

FIG. 1. NARROW BOAT CANALS—SINGLE LEAF GATES.

Sectional plan and elevation of gate.

a Balance beam. *c c* Rack and pinion. *b b* Shuttles. *d* Operating gear.

a catchment area of 75,000 square miles, the Danube with an area of 306,000 miles, and the Volga with 527,000 miles, will serve as examples of the rivers of the old world; while the Mississippi, the "Father of waters," with 982,000 miles, will suffice for the new. The claim that the little English barges showed the way is neither ill-founded nor exaggerated, as although canals were constructed in very early days—long before either Leonardo da Vinci or the Dutch engineers were thought of—and traffic was borne upon their waters in quaint high-sterned barges, yet it was not until the object lessons which were presented by the English canals, by the development of their traffic, and by the commercial value of that development, were slowly learned and still more slowly applied in practice, that Continental engineers either in the East or in the West endeavoured to follow the lead which the islanders had given them; and so began the course which has led to such immense movements of trade and to such great developments of commercial enterprise.

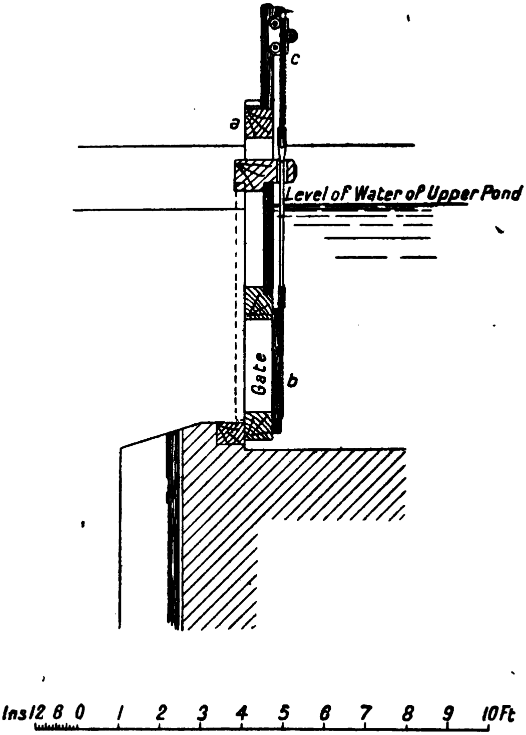
c
a
Level of Water of Upper Pond
Gate
b
Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 Ft

FIG. 2. NARROW BOAT CANALS—SINGLE LEAF GATES.

Section of gate showing shuttle.

a Balance beam. *b* Shuttle. *c* Rack and pinion.

Beginning, then, with the narrow boat canals of the early part of the eighteenth century, and with the details of the works on those canals which are especially in point so far as the present purpose is concerned, the form and the manner of construction of the gates by which the locks of those canals were controlled will be seen from Figs. 1 and 2, which also show the arrangement (something of hardness of heart as well as clearness of understanding will be required before this arrangement will be admitted to be describable as "machinery") by means of which the gates were opened and closed by the man who worked them.

If directness in design, simplicity in construction, and effectiveness of purpose, be the *beaux ideals* of competent engineering, then it may be claimed that the operating machinery for the gates of these small locks held high place in their own day, as they fulfilled all the conditions thus formulated, and not only fulfilled the conditions, but enabled the work to be done at a minimum cost. The machinery really consisted of a combination of the person of the man in charge of the narrow boat, and of the moments of the balance lever which was attached to the upper part of each gate. The force was supplied by the bargee, who vigorous in action as in manner of speech, bore down with all his weight on the outer end of the balance lever, dug his heels into the ground, and in little more time than it now requires to tell the tale, swung the gate open, hauled in his narrow boat, and closed the gate behind the craft. In the history of the growth of dock and lock machinery, as in many other like narratives, the man and the lever were the component parts of the first machine.

But as has already been insisted upon, water transport of goods proved itself to be a phenomenal success, and trade grew and expanded to an extent which up to then had been unheard of. To meet the needs of the larger trade, larger boats were demanded and larger locks and gates were constructed, though no change in the machinery, therefore, was suggested as yet. The limit of possibility for the single-leaf gate was, however, soon reached, and lock gates were constructed which had two leaves instead of one. There was no novelty in this: "two-leaved gates" were known in "great Babylon" nearly three thousand years ago; yet in the introduction of such gates as part of the equipment of a dock entrance or a canal lock, a decisive step was taken, through which access had been found into the way which, as our own eyes have seen, was to lead to the entrances and the locks which were to accommodate the "Aquitania" and the "Vaterland."

For the time being the advance from single-leaf to two-leaved gates had no effect upon the design of the machinery for the operation of the gates. The only difference was that two men instead of one as before were required to open and close the two-leaved gates. The practical result, therefore, was that canal companies were compelled to appoint a resident lock-tender at each site, whose duty it was to work the leaves of the gates on the side of the lock adjacent to the "lock-house."

As the eighteenth century advanced the volume of merchandise carried by canal continued to increase and led to a steady advance in the dimensions of locks and entrances, and *ipso facto* led to a development of the gear by which the gates were moved to and fro.

The development of the gear, as is usual in cases of well-marked advance in mechanical engineering, proceeded through two stages. In the first of these stages manual effort was aided and reinforced by mechanical devices through which the effect of muscular energy was multiplied at the cost of a corresponding diminution in the speed of the movement. In the second of the stages, the effort was superseded by extraneous power of one sort or another, which was applied through machines which were primarily of comparatively simple design, but which became more and more complex, as the problems to be solved themselves increased in complexity.

The initial step in the first stage of the development was simple to the point of crudity; but it was effective, and it rendered the increase in the width of locks and in the weight of the leaves of lock gates, already referred to in this chapter, feasible and practicable.

The lock builder (it seems to have been Brindley himself) who found that the leaves of his gates were too heavy for ready movement, and that in the process of that movement, the resistance with which they met in their passage through the water was too much for his lock tenders and bargees to overcome, planted two stumps at each end and on each side of his lock, one stump in each pair being above and the other below the balance lever of each of the several gate leaves; fitted each stump with an eye-bolt, and added another eye-bolt to the outer end of the balance lever; he then connected one of the blocks in a pair of blocks and a fall, with the eye-bolt in the balance bar, and left his gate workers to attach the other block to either one stump or the other, according as it was desired to close the gates against the sill, or to open them. Many other mechanical devices were used for the operation of gates in dock entrances and in locks, but attempt at description of them or even reference to them is unnecessary, as for the most part they are obsolete.

One or two of the inventions, or adaptations, are, however, in a different category, and not only still survive and do useful work, but are capable of being further developed within the field of their limitations.

In the quadrant and pinion type of gate machine, for instance, manual power was applied, with much directness and with a minimum of loss, to the resistance which was to be overcome during the movement of the leaf of the gate; particularly as sliding friction in the parts of the machine itself was eliminated to a large extent, and rolling friction was substituted therefor. The quadrant and pinion machine was, therefore, worked with sufficient ease by an ordinary gate attendant, who made his initial effort, thus supplying power to overcome the inertia of the stationary gear and of the gate to which the gear was attached, and then easily and without strain kept that gear in motion until the stroke of the opening or closing leaf was completed. The machines were not costly to begin with, and their maintenance charges were always very moderate, so that it is not surprising that they obtained a considerable vogue in the industrial districts where the demand for the enlargement of the waterways was most insistent. One example out of a series of many gate machines of the quadrant and pinion pattern which are still in continual daily work, will be seen in Figs. 3 and 4. The machine illustrated in these figures is one out of the six which work the leaves of the gates in the "small lock" at Saltersford on the Weaver Navigation* in the County of Cheshire. The "small lock" is 25 feet 2 inches in width, the

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* The Weaver Navigation joins the estuary of the Mersey at Weston Point, near Runcorn. The Navigation serves the Cheshire salt district, in that the salt derived from the subterranean brine streams in that district is conveyed along the Weaver and the Mersey to Liverpool, for shipment to almost all parts of the earth. The Navigation (which has been many times extended and enlarged) is one of the more important of the works for the canalization of rivers which were undertaken in the first half of the eighteenth century, which was the great era of English river canalization; just as the latter half of that century was so much a special period of actual canal construction, that the activity which was genially described as the "canal mania" took definite form in 1790.

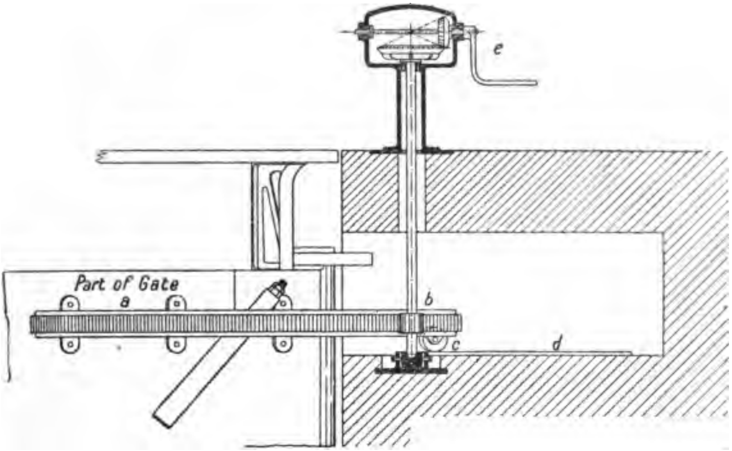

FIG. 3. GATE MACHINES—WEAVER NAVIGATION.

Sectional elevation of quadrant machine.

a Quadrant. *b* Pinion. *c* Guide wheel.
d Guide wheel path. *e* Operating gear.

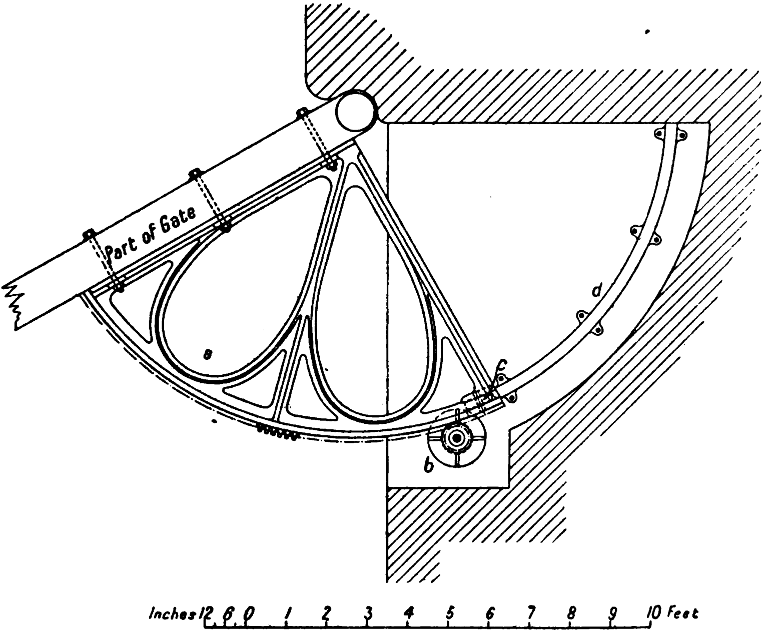

FIG. 4. GATE MACHINES—WEAVER NAVIGATION.

Plan of Quadrant Machine.

a Quadrant. *b* Pinion.
c Guide wheel. *d* Guide wheel path.

gates therein are timber built, the width of each leaf is 15 feet 3 inches, and the maximum and minimum depths of water on the sill are, under normal conditions, 23 feet 6 inches and 15 feet respectively. The gates, although perhaps not the widest, are probably the deepest to which the quadrant pattern of machine has been fitted, a fact which gives the example a special interest. The existing machines have been in daily work for forty years, and there seems to be no reason why, with reasonable repairs and renewals, and barring accidents of a disastrous sort, they should not continue at work for as many years more.

Quadrant machines have, however, certain inherent disadvantages to which attention should be drawn in such a manual as this is intended to be. The quadrant must of necessity be attached in each case to the leaf at a level at or above that of high water; and must, therefore, be fixed far above the centre of the pressure on the gate; it is, moreover, particularly liable to damage by a tug of small beam which may tow barges into the lock from the up-stream end; and the formation of the opening behind the gate recess for the housing of the quadrant when the opened leaf is lying in the recess becomes a more difficult problem as the width of the lock, and consequently the size of the quadrant, is increased. But the overcoming of difficulties of construction is the *raison d'être* for the existence of the engineer, and the facilities which modern methods present leave the engineer who finds such difficulties insurmountable without excuse.

The philosophy of the quadrant machine lay in the adaptation of the principle of the spur wheel and pinion to the working of dock gates. That principle carried a little farther, led to another common-sense and unpretending type of machine which is still largely used, particularly in cases in which frequent movement of the gates is not required, such as those of entrances to dry docks, laying-up basins, etc. The modified machines were formed into compact winches, or crabs, having horizontal shafts and being fitted with chain drums, on which drums, at the first, iron chains, and in more recent days steel ropes, were coiled, by means of which chains and ropes, the gates and the winches were connected and the leaves of the gates were hauled to and fro.

The outstanding feature in the gate machine of the winch type was the introduction of these connecting chains, as this turned out to be the first step in an evolutionary line which seemed to be a true line of progress, but which in the light of more complete experience must be regarded by engineering men of the present day as an ultimately misleading line ; a line which when pursued beyond the limits of its convenience led to inconsistency in construction as well as to the clashing of interests in development, and which, therefore, must of necessity be abandoned now.

There was another feature in this step in the development to which some allusion should be made, if only for the fact that it seems to be a distinct case of recurrence to type. When winch machines of the original pattern were installed at any entrance of a lock it was necessary that two separate machines should be supplied for each leaf of each gate, and should be fixed at each side of the entrance, one for opening and the other for closing the leaf to which the machines are attached; and it will not be difficult for the engineer to recognize that such arrangement has a family likeness to the gear for the narrow boat locks, previously described, of which the block and fall were a feature.

When the winch machines were first introduced, the gate chains were led directly from the barrels of the winches to the fastenings in the gates which were fixed at levels fairly high up in the mitre posts. But in working with this arrangement difficulties were encountered which affected injuriously the fastenings in the comparatively light timber-built leaves of the gates, and not infrequently the craft themselves, while in the act of passing, were fouled by the festooning of the chains. Consequently the fastenings were moved lower and lower down the mitre posts until they reached the true point of attachment, i.e. the centre of the pressure of the water against the leaf, that is to say, at a depth of two-thirds of the depth of the immersed area of the gate, measured from the surface of the water. As a further step the chain was led horizontally to the underside of a sheave which was fixed in the wall of the gate recess, and from which the chain was again led vertically (or nearly so) in a groove in that wall to the winch barrel. Later on, as the dimensions and the weights of the gates grew still greater, each chain was led to a combination of horizontal and vertical rollers which revolved on shafts in bearings prepared for them in a cast iron box, which box was fixed in a special " chain way " square in section and built in the side-wall of the lock or entrance; sometimes with a horizontal tunnel (at the inner end of which the chain rollers were fixed) and a vertical shaft, over which the winch was placed; and sometimes with an inclined shaft, at the mouth of which the rollers were erected in a wall box, and thus served to lead the chain to the winch at the upper end. Each system had its advocates, but, as a matter of fact, there was nothing to choose between the two. The winch type of gate machine and the chain or rope attachment which pertained to it had two advantages, which enured to the survival of the type and to the repetition thereof in various circumstances. The first of these advantages was that the motive power could be attached to the gate at a point in the mitre post which was coincident with that of the centre of pressure on the gate, and the second was that the type could readily be adapted to operation by power of any sort, whether steam, hydraulic, or electric.

POWER ACCELERATES THE RATE OF PROGRESS OF THE DEVELOPMENT

In these pages consideration has hitherto been given to methods in which gates were operated by means of hand power only, whether that power was applied directly as at the first, or through the mechanical devices by which it was supplemented and multiplied (at a commensurate loss of time) in later days.

These later days may be regarded, without vital inaccuracy, as having been coincident with those in which the eighteenth century drew to a close, when canal construction reached its zenith and proceeded until it was first of all checked by the "canal mania" and ultimately arrested by the mania for railway construction from which the United Kingdom suffered at a later period of its history.

The days were marked by political instability, they were days of revolution and of almost unbroken war and strife; but notwithstanding this they were days of marked mechanical progress and of amazing commercial advance. It was in those days that men learned the real significance of the seams of coal which lay beneath the soil in England and in Scotland side by side with its stores of iron ore. It was in those days also (1765) that James Watt, the Greenock instrument-maker, completed and published the particulars of his improvements of the steam engine, and that Hargreaves the carpenter, Arkwright the barber, and Crompton the weaver invented and introduced the spinning jenny, the spinning frame and the spinning mule, all of them epoch-making devices.

In 1785 another genius of mechanical bent, Cartwright, then a curate in an obscure country parish, invented the power loom and thus completed the edifice which had been built up by the Lancashire tradesmen.

About the same period (1776) Adam Smith, the astute Scottish philosopher whom the quaint ways of the Scottish people of his time converted into a Commissioner of Customs (just as they converted Robert Burns into a gauger), published his treatise on the "Wealth of Nations." The work of the philosopher crowned that of the men of mechanical genius with which it was so nearly concurrent; and the two combined paved the way for the immense increase in the world's industry and commerce which was to take place in the nineteenth century.

As a result of these and other inventions and improvements steam-driven machinery slowly but surely superseded manual labour, and power-driven machines became essential factors in civilized existence.

Railways—beginning with the tiny colliery track from Hetton in the County of Durham to the banks of the Wear at Sunderland—began to prove their worth and to show what unlooked-for possibilities they possessed, and were gradually extended until their articulation covered the Islands like a net; while concurrently, vessels built of iron and propelled by steam power were introduced upon the canals, the rivers, and the seas.

With such a mechanical environment as has been indicated, it was inevitable that in the working of dock and lock gates, hand power should be supplanted by artificial power. The development followed the line of least resistance, so that at the outset hand winches at the dock entrances became steam winches, in the sense that they were steam driven by means of steam engines, the power of which was applied through line shafts which were laid in trenches along each side of the entrances, and the several winches on each side were engaged in turn by revolving shafting through the media of clutches or cone connections. Forty or fifty years ago this was a favourite system for the working of cranes for the handling of cargoes on a dock quay, as well as for that of winches at a dock entrance; the system had advantages, but it was not economical; the line shafting absorbed a great deal of the power generated, and frequently was allowed to run for hours without performing any useful function or duty; and what was worse, when a sudden demand was made for a special supply of power the shafting frequently refused to respond. These difficulties were overcome by substituting steam pipes for the line shafting and by concentrating the winch and the steam engine on the same bed-plate. This was the genesis of the type of steam winch with which the ubiquitous steamship, whether tramp or liner, has familiarized the world, and was a distinct advance. But steam supplied through a long underground steam pipe was never anything but a wasteful medium for the supply of energy to machines, whether for the purpose of moving gates or for any other purpose, particularly when handicapped by the low pressures and the ineffective methods of preventing loss through radiation, which were in vogue about the middle of the nineteenth century, which is the period at which we are arrived. Some superior means of distributing power was, therefore, urgently required, and as things fell out, was supplied in a way which was revolutionary rather than evolutionary.

CHAPTER II

THE ARMSTRONG GATE MACHINES

In the year 1847 Mr. W. G. Armstrong, the junior partner of the well-known firm of solicitors in Newcastle-upon-Tyne—Donkin, Stable, and Armstrong—retired from the practice of the Law because of the increasing interest which he had come to take in questions relating to the application of hydraulic power to matters of commercial utility, questions at which he had been steadily working for ten or eleven years. In this period Mr. Armstrong had *inter alia* designed a hydraulic crane in which the operation of lifting was performed by a single stroke of a piston which worked within a press, and which was operated by means of water derived from the mains of the local water company.

In 1845 a Company which was subsequently known as the Whittle Dene Water Company was constituted in Newcastle-upon-Tyne, and Mr. W. G. Armstrong was appointed the first secretary of the Company. This led to the formation of a second Company, called the Newcastle Cranage Company, of which the five partners, including Mr. Armstrong, were the men who, in 1847, founded the Elswick Works and became the first partners in the Elswick Company, for which they found amongst themselves the modest capital of £22,500.

Shortly after his emancipation Mr. Armstrong—much better known and remembered by us now as Lord Armstrong of Cragside, and recognized and revered as one of the great engineers of the nineteenth century—took a further step, which proved to be epoch-making in the process of the evolution of hydraulic machinery, for he invented the hydraulic accumulator. Mr. Armstrong's first idea was to obtain the pressure for operating his machines, either directly from a stream or indirectly through the mains of some domestic water supply, the power in either case being derived from the force of gravitation. He found that in many cases power so derived was irregular and insufficient, and that it rendered the machinery cumbrous; and the second step which he took was to supply the necessary head artificially by the pumping of water by means of a steam engine into a high tower previously built to receive and to distribute the water. The third and final step was the substitution for the high tower of an accumulator in which the pressure is supplied by the pumping of water into a main against a head provided or represented by means of a weight concentrated upon a plunger bearing upon the water in a vertical cylinder, which cylinder is itself connected with the main into which the pumping takes place. Under these circumstances the only limit to the working pressure is that due to the power of the pumping plant to supply the quantity of water required, and the extent of the capacity for resistance to pressure of the material in the vertical cylinder in which the plunger works and in the distributing main. As the result of the third and final step in the development referred to, the pressure under which hydraulic machinery was operated was at once increased from 100 lb. per square inch to 600 lb., the 600 lb. being shortly afterwards increased to 700 lb., which was a standard for many years, but which in recent years has been again increased to 800 lb. and even to 1000 lb. per square inch in many cases.

The products of the Elswick works which the five partners in the Newcastle Cranage Company founded have made their way to many parts of the world, and their fame has gone to the ends of the earth; but it is particularly with the Armstrong gate machines that we are concerned in these pages.

The earliest gate machinery of which there is record as having been made at Elswick, was fitted in the lock entrance to the Old or Alexandra Dock at Grimsby, in the year 1851, just about the time of the introduction of the hydraulic accumulator. In December, 1850, a tender for the whole work involved in the construction and erection of these gate machines was submitted by Mr. Armstrong to Mr. J. M. Rendel, an eminent dock engineer of the time, who was then acting for the Manchester, Sheffield, and Lincolnshire Railway Company—a Company which has since greatly extended its borders and its operations and has become known far and wide as the Great Central Railway Company, to whom the Grimsby Docks belong and by whom the Immingham Docks are leased. The tender was accepted and the work was in course of time duly completed by the Elswick Company.

The lock leading to the Old Dock at Grimsby is 145 feet in length by 35 feet in width, and is fitted with six pairs of gates altogether, which gates were originally operated by means of twenty-four Armstrong machines. The leaves of the gates were opened by chains which were wound around and unwound from grooved barrels, the barrels in turn having been driven through mitre gearing by means of a curious arrangement of a sprocket wheel and a chain. In this arrangement the chain was connected with and was hove backwards and forwards by a piston and rod which travelled in and out in a large horizontal cylinder, into which water was admitted under low pressure. The pressure in the cylinder was due to the head derived from a tower 200 feet in height, into which the water was pumped. The tower is still in existence and, so far as the records go, commemorates at once the first attempt to work gate machines by means of hydraulic power, and the first practical application of the method for the supply of that power already alluded to and described as the second step taken by Mr. Armstrong in developing his scheme of hydraulic supply.

In the design of these gate machines provision was made for working each machine by hand as a stand-by in the event of a breakdown of the hydraulic machinery. The hand gear in each machine was worked by a horizontal shaft fitted with handles at either end, to which shaft a worm was keyed which engaged in a horizontal worm wheel, which in turn operated the bevel gear already referred to, by means of which the grooved barrel was caused to revolve. The horizontal and vertical shafting and the worm and worm wheel were housed in a capstan-shaped casting by which each gate machine was crowned. The whole design, whether regarded from the point of view of the general arrangement or of the mechanical details, has now a quaint, not to say an archaic, appearance. But the machines marked a stage in the development which we are considering; they worked satisfactorily for many years before they were replaced by modern high pressure jiggers, and although Mr. W. G. Armstrong's accumulator device, which formed the third step in his evolutionary way, was not embodied in their design. It will be seen from Fig. 5—in which the general arrangement and features are shown—that the machines at the Old Dock contained the rudiments of modern and more highly developed gate machines.

Some three years later (in 1853) Messrs. Armstrong and Co. constructed gate machinery for the entrance locks to the West India Docks, the Isle of Dogs, and to the East India Docks, which

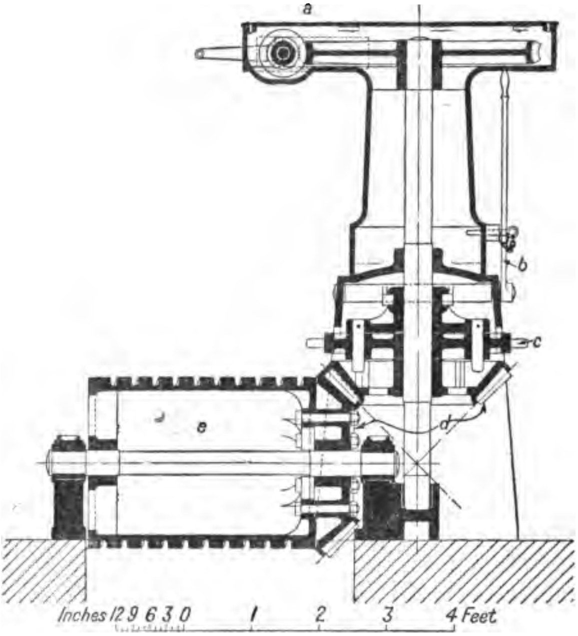

FIG. 5. GATE MACHINES—GRIMSBY DOCKS.

Cross-section of original winch machine.

a Hand gear. *b* Attachment for hand gear.
c Sprocket wheel for chain to hydraulic piston and rod.
d Mitre gearing. *e* Chain barrel.

are situated at Blackwall. The original lock entrances in the West India Docks were 45 feet in width, while those in the East India Docks were 47 feet 6 inches. In both cases the gate machines consisted in the main of two high-pressure cylinders and rams which were laid side by side at right angles to the lines of the lock walls and on beds which were inclined at an angle of 1 in 6 with the horizontal. The rams and their cylinders were fitted with multi-

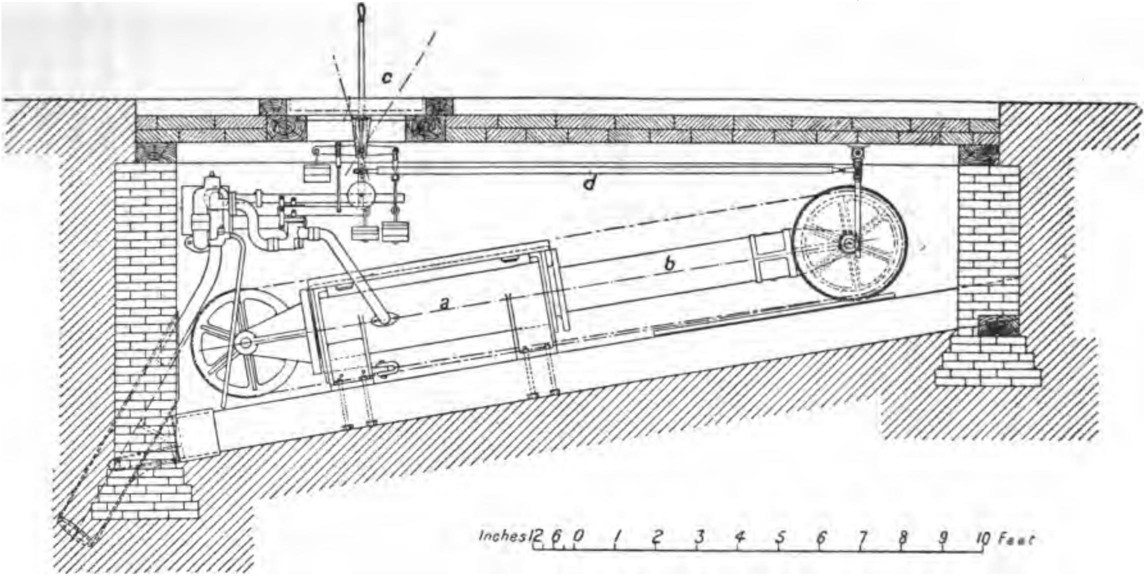

Fig. 6. Gate Machines, East and West India Docks, London.

Sectional elevation of hydraulic cylinder machine.

a Hydraulic cylinder.
b Hydraulic ram.
c Operating lever.
d Automatic cut-off.

plying sheaves and were connected with the gates by means of chains. This type of machine found much favour in the eyes of dock engineers and has been largely used in almost all parts of the world. The arrangement of the machines as erected at the West and East India Docks is shown in Fig. 6.*

In 1863 and 1864 another type of the Armstrong gate machines was introduced. The type may be described as that of the hydraulic winch machine, as the barrel in each machine around which the gate chain (whether for opening or closing) was wound, was operated by means of a hydraulic winch in which two oscillating cylinders drove a crank shaft. At the outer end of this crank shaft a pinion was keyed, which engaged in a spur wheel which was again keyed on the barrel shaft. In some cases the hydraulic winch was fixed in a horizontal position, as in the lock entrance to the Penarth Docks (on the north side of the Bristol Channel, near Cardiff), the width of which is 60 feet; in others in a vertical position, the engine being placed beneath the chain barrel, as in the lock entrance to the Canada Dock, Liverpool, which is 90 feet wide. At a little later period gate machines of a similar type were constructed for the sea and junction entrances of the Hendon Dock at Sunderland, and of the entrance to the Delamere Dock at Western Point in Cheshire, where the Weaver Navigation joins the estuary of the Mersey.

These machines were all fitted with alternative hand gear for working the gates in times of breakdown; the power being applied in each case through capstan bars, which when required were socketed into a capstan head which in turn drove bevelled gearing. The capstan head was fixed below the level of the dock wall, in the manner shown in Figs. 7 and 8, which illustrate the pattern of the gate machines which were erected at the Canada Dock, Liverpool. The placing of the whole of the hand gear below the quay level in all these machines was a great improvement, as by this means the obstruction to the lock quays caused by such hand gear as was provided at Grimsby, where the gear with its encasing castings, though seldom used, stood at all times several feet above the level of the quays behind the lock walls. The hydraulic winch type of

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* The year 1855 marked a momentous era in the history of the Elswick Works; for the manufacture of ordnance in the form of the famous Armstrong guns was then begun in those works. As is well known, this industry extended in a degree which surpassed the most sanguine expectations of its promoters.

Armstrong machinery displaced the ram and cylinder type to a certain extent and held the field up to the year 1877, when the machines for the lock which forms the entrance to the dock which was built at Bristol, were constructed with rams and cylinders of a design which was in large measure a reversion to that used for the entrances to the West and East India Docks, already described;

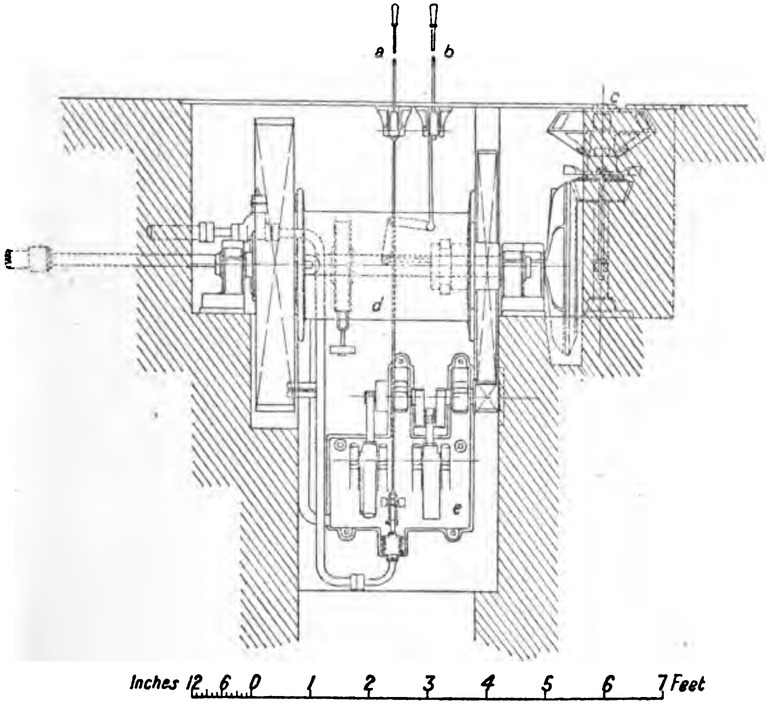

FIG. 7. GATE MACHINES, CANADA DOCK, LIVERPOOL.

Side elevation of hydraulic winch machine.

a Operating lever. *b* Brake lever. *c* Hand gear.
d Chain barrel. *e* Hydraulic engine.

except that the cylinders were fixed on lines parallel to those of the lock walls, and were laid on horizontal beds instead of inclined bases, and also that the chains by which the gates were connected with the machines were attached to the foot of the mitre post of each leaf, the object being to reduce the difficulty due to the festooning of the chain, which was already beginning to be felt.

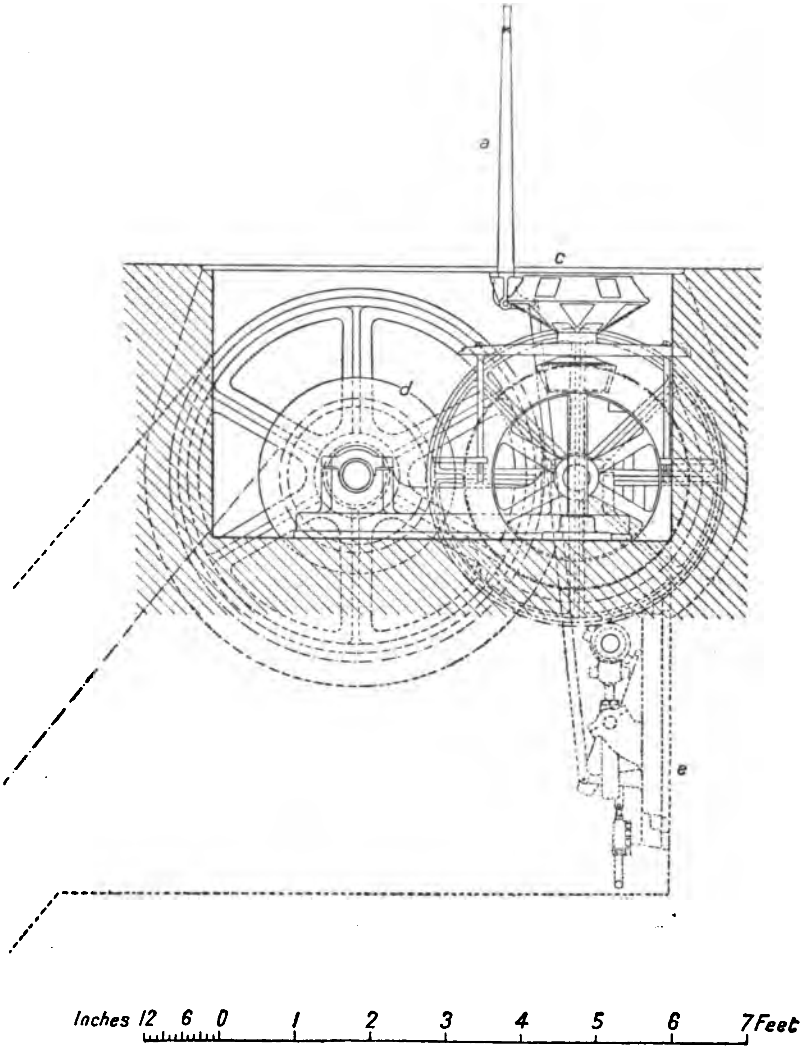

FIG. 8. GATE MACHINES, CANADA DOCK, LIVERPOOL.

End elevation of Hydraulic winch machine.

a Operating lever.	*c* Hand gear.
d Chain barrel.	*e* Hydraulic engine.

Passing from the Thames and the Mersey to the Scheldt and to the enterprising and progressive port of Antwerp, which is situated thereon, and in which such widespread interest is centred at the time of writing, not only because of the disaster which overtook the City of Antwerp in 1914, but because of the immense possibilities which lie in the future for that city, we find there a type of hydraulic gate machine which differs from all the types hitherto described in these pages, but to which a reversion will be found when we come to deal with more modern gate machines which are operated by means of the electric current.

In 1877 the Government of Belgium and the Municipality of Antwerp, who had had for some years one of their many schemes for the extension of harbour and dock accommodation at Antwerp in contemplation, entered into a contract for the construction of a new quay wall on the easterly or concave side of the River Scheldt and for other collateral works. The river wall which was then proposed was over two miles in length, and in its course a lock entrance was to be formed, through which communication was to be provided between the River Scheldt and three barge docks which were to be built behind the quay wall. The whole of these works were duly completed, were of considerable extent (they cost over £1,500,000), and were of immense benefit, not only to the trade of the Port and City of Antwerp, but to that of the whole Belgian nation. The entrance which was formed in the long wall had a width of 42 feet 6 inches at each of the two gateways which were formed in it, and a width of 82 feet 6 inches in the basin which intervened between these gateways. This entrance was fitted with four pairs of gates, and the machines by which these gates were operated provide the feature of special interest to which it is desired to direct attention here.

The gate machines were designed and constructed at the Elswick works by Messrs. W. G. Armstrong and Company. The machines are of the pinion and rack type, and therefore differ in design from any of the prior machines which had emanated from Elswick. This type does not appear to have been reproduced at any other port to which Messrs. Armstrong and Company's machines have been supplied, and as the pinion and rack arrangement, in a more crude form, had been in use for the working of the gates in the earlier docks at Antwerp, the presumption is that the adoption of this particular type in the case under consideration was due to local circumstances.

The general features of the design are shown in Figs. 9 and 10. It will be seen from these illustrations that the hydraulic engines for the machines are of the horizontal pattern, and that each engine has two oscillating cylinders, which drive a horizontal shaft to the central portion of which the body of a sliding clutch is keyed. On the shaft are two bevel pinions, one of which is placed in proximity to each of the two journals of the shaft. When these pinions (or either of them) are out of gear with the sliding clutch the shaft runs loose through the disengaged pinion or pinions; while to drive either pinion the sliding body of the clutch which is keyed to the shaft, is engaged with that pinion according as it may be desired to open or to close the leaves of the gates. The pinions drive a vertical bevel wheel which revolves in each direction, as it may itself be driven by the pinion on the right or on the left-hand side, and so drives in its turn a horizontal shaft. To the end of this horizontal shaft a second bevel pinion is keyed, and that again drives a horizontal bevel wheel keyed to a vertical shaft, of which the lower end works in a footstep, having above it a pinion keyed to the shaft. This pinion moves (backwards and forwards) a rack and boom which is pivoted to the back of the leaf of the gate, which it controls and thus moves the leaf inwards or outwards. It will be seen that one machine serves for both the purposes of opening and of closing the leaf to which it is attached.

The design of these Antwerp machines is of more than ordinary interest, both as a step in a particular line of development and as it would appear that they may be regarded as the prototype of the pinion and rack machines which have been used somewhat largely for working gates since the electric current has been employed for the motive power. Of these the gates on the original Kiel (or Kaiser Wilhelm) Canal are an example, as well as the gates in the locks on the new Erie Canal, of which a detailed description will be found in later chapters of this book.

Between the years 1888 and 1893 a large number of machines were constructed for the operation of the gates (*a*) in the locks which form the entrance to the Manchester Ship Canal from the estuary of the Mersey; (*b*) in the three intermediate locks on the waterway; and (*c*) in the locks through which the Manchester Docks are reached. In all fifty-six complete sets of machinery

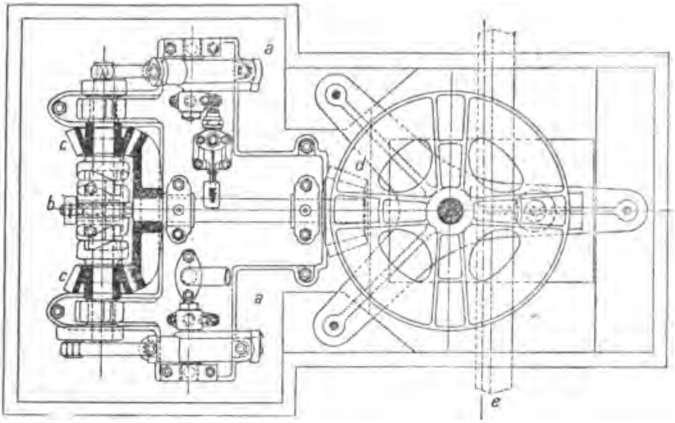

Fig. 9. Gate Machines, South Barge Dock, Antwerp.

Plan of hydraulic pinion and rack machine.

a Hydraulic engine.	*b* Reversing gear.	*c* Bevelled gear, first motion.
d Bevelled gear, second motion.		*e* Rack and boom.

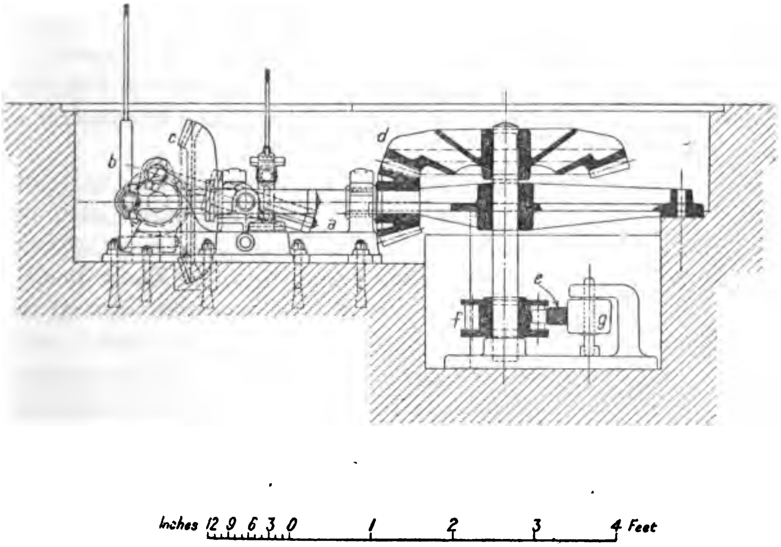

Fig. 10. Gate Machines, South Barge Dock, Antwerp.

Cross-section of hydraulic pinion and rack machine.

a Hydraulic engine.	*b* Reversing gear.
c Bevelled gear, first motion.	*d* Bevelled gear, second motion.
e Rack and boom.	*f* Pinion for rack and boom.
g Roller guide for rack and boom.	

were constructed and erected for the Ship Canal gates. The design and general arrangement of these machines are shown on Figs. 11 and 12. It will be seen from these illustrations that while the ship canal machines are of a type generally similar to those described for the Bristol lock, the arrangement of the chains by which the gates are connected with the rams, presented a new development. The chains, both for opening and closing purposes, were carried in each case along the upper rib of the gate and over a vertical guiding sheave; the chains, whether on the inside or outside of the gate, were then passed downward to swivel brackets which were bolted to the leaf at or about the centre of pressure thereon; the swivel brackets were swung to or fro by the stroke of the chain, and were thus kept in line with the outer length of the chain which was in each case carried from the swivel bracket to the fast end, which formed the termination of that length. The fast end was originally intended to be shackled to an anchor bolt in the side of the lock wall, but was eventually secured to a lewis bolt fixed in the granite work of the lock sill, against which the particular leaf closed. This system of chain connections became known as the "overgate chain arrangement," and for a number of years the overgate type of gate machine and connections was regarded as a standard, and was widely adopted.

At or about the same time, the late Mr. H. M. Brunel suggested a form of direct acting gate machine which was constructed by Sir W. G. Armstrong and Company, and was in the first instance applied to the gates in the original entrances to the Barry Docks, in South Wales. These direct acting machines were also of the ram and cylinder type, but in the Barry gates the ram was in each case attached directly to the leaf of the gate which it controlled; while the cylinder was fitted with bearings of the vertical trunnion pattern, and when in operation was oscillated in a horizontal direction so as to accord with the angular variation of the ram as the gates moved, whether in an inward or an outward direction. Each ram was connected with its gate at such a level that the whole machine was submerged at the higher stages of the varying levels of the tidal waters. This was an obvious disadvantage and caused difficulties of various kinds, with the result that the direct acting machines were modified and developed by the Elswick firm into what is now known as the "gate beam" or "crocodile"

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pattern. In the gate machines thus modified the cylinders are fixed at or about the coping level of the lock, and the power of the ram is applied through a horizontal beam which is attached at the inner or shore end to the anchor block for the gate, in such manner that the heel post is freed from direct strain; while at the outer end the beam is secured to the mitre post. A further modification effected in these later and improved machines is that the cylinders are all fixed in position, the oscillation being done away with and the stroke of the rams being maintained always in the same straight line (whether the movement be inward or outward), the variation in the angle between the line of the cylinder and that of the back of the gate being overcome by the swing of a connecting rod which is inserted between the end of the ram and the gate. This pattern of machine was constructed at Elswick for, and was in the first instance fitted to, the gates in the Lady Windsor Lock at Barry. The general arrangement and method of construction of the machines in question are shown in Figs. 13 and 14. The Lady Windsor Lock, in which there are three pairs of gates, was constructed as an alternative entrance to the Barry Docks, and the works therefore were begun in 1891.

The modified form of direct acting gate machine was also fitted to the gates in the 100 foot lock which now forms the entrance to the new Avonmouth Dock, which was built by the Bristol Corporation on the north side of the River Avon at a distance of some 6 miles below Bristol, and was opened in 1908. Figs. 15 and 16 illustrate the gate machines with which the entrance to the new Avonmouth Dock was equipped.

In certain of the gate machines of the direct acting hydraulic ram type as modified by the experience gained in working, the horizontal beam or "crocodile" is attached at the inner end to the anchor block in the manner already described, while the outer end is secured to the upper rib at a distance of about one-third of the length of the gate from the mitre post, by means of a bracket which is, in fact, a continuation of a vertical diaphragm which is carried upwards from the sill beam of the gate to the uppermost rib. The purpose served by the diaphragm is the more complete distribution of the strains over the whole structure of the leaf of the gate. Machines of this pattern have been employed for some years past in the working of the gates of the more recent docks in the Port of Leith. Fig. 17 illustrates the form and arrangement of the gate machines of the type which are in use at the Leith Docks.

These direct acting machines furnish a further example of mechanical atavism. The fact is that in the course of time, experience showed that concurrent lines of development in gate machines and in the vessels for the sake of which the machines were evolved had clashed, the concurrent lines being (1) those of the cargo steamer which under the stress of the necessity for the conveyance of the maximum amount of cargo at the least possible cost, developed until the midship section of the steamer took a more box-shaped form, and (2) those of the gate machines in which the necessity for increased dimensions of locks and for the rapid and effective movement of lock gates, had led to the convenient system of connecting the gates with the machines by means of the chains already described, until a point was reached in the dimensions of the steamer at which the box-shaped ship and the connecting chains ceased to be compatible with each other, and the special form of chain connection which had been evolved was abandoned, and the original direct acting type of gate machine, which at first appeared as a combination of a balance lever and a bargee, and later in that of a quadrant and pinion, was reverted to in the modified form of the hydraulic press and piston which has been described and illustrated in these pages.

CHAPTER III

CHAIN (OR ROPE) CONNECTIONS *REDIVIVUS*, DEVELOPMENTS NEW AND OLD

IN 1914 a new dock, which is situated on the northerly side of the River Humber and within the precincts of the City of Hull, was opened by His Majesty King George V, and was by him named the "King George Dock." Prior to that time the dock had been known as the Hull Joint Dock, having been constructed by, and at the joint cost of, the North-Eastern and the Hull and Barnsley Railway Companies. The King George Dock is the most modern of the docks in the great Yorkshire port, and may therefore be regarded as embodying the latest results of the experience which has been acquired in dock construction and working during Hull's long history as a seaport town. The new dock is entered from the Humber by means of a lock which is 85 feet in width and which is fitted with three pairs of gates. The lock entrance is equipped with gate machines of a design which differs from all the machine designs which have been described in the foregoing pages, or which will be referred to in the pages which follow. It may therefore be reasonably claimed that the gate machines in the new lock at Hull represent a stage in the evolution of English built machines, as they embody certain distinct features of novelty. Seeing that they are at the time of writing the last word in the design and construction of dock machinery in Great Britain, it seems to be desirable that a detailed description of the gate machines should be included in this work, particularly as they carry in themselves a recognition of the desirability of introducing devices into gate machine construction through which the decided advantages possessed by chain or rope connections may be preserved, and yet the special disadvantages in the case of modern locks which have been built for the accommodation of vessels of great beam and of box-like section may be avoided.

The gate machines in the new Hull lock are worked by means of hydraulic winches. These winches are in their general design similar to those which were introduced by Sir W. G. Armstrong and Company (described and illustrated on p. 28 *et seq.*), but differ from the Armstrong gate winches in some important details, notably in that the hydraulic engines by which the winches are driven are reversible,* and consequently that one winch serves for both the opening and the closing of one leaf of the gates.

In each of these winches a three-throw crank shaft which is driven by three oscillating cylinders, has a pinion keyed thereon; this pinion engages in a spur wheel which is keyed to an intermediate shaft, to which another pinion is keyed which in its turn engages in a spur wheel keyed to the third motion or barrel shaft. The grooved barrel of the winch is secured to this third motion shaft. The three cylinders of each winch are each controlled by an independent slide valve which is worked by a lever fixed to the cylinder trunnion, and the reversal of the winch is effected by a hydraulic servo-motor. All the reversible winches are fitted with hand gear of the underground capstan head pattern, and are fixed in pits which were constructed for their reception in the lock walls, so that they present no obstruction to the working of traffic or to other movement on the quays of the lock. The levels of the bottoms of the pits are in all cases above the level of high water of spring tides, the pits are consequently not subjected to tidal inflow or to other damage by water. The hydraulic winches are all capable of developing 25 b.h.p. at 110 r.p.m. with a hydraulic pressure of 700 lb. per square inch. Beneath each of the pits in which the hydraulic winches were erected, a vertical shaft or ropeway was formed in the wall of the lock; the shaft terminates in each case in a horizontal trunk or tunnel, which provides a communication between the vertical shaft and the side of the gate recess. Each of the horizontal trunks is 6 feet in width and 6 feet in depth, and has in the centre of each of its side walls a rail which is secured to the masonry for a considerable part of the length of the trunk. On the rails in the side walls a heavy crosshead slides in and out; this crosshead serves as the support of the inner end of a steel strut which is secured to the crosshead by means of a pin connection. Each strut is 48 feet in length over all, and has a stroke of 39 feet 10 inches. The strut is built up of steel plates riveted together in such manner as to be absolutely watertight (each strut was tested after construction to an internal hydrostatic pressure of 29 lb. per square inch) and, being always submerged, has displacement sufficient to compensate for the weight of the materials of which it is composed. The outer end of each strut is secured to the back of the gate by means of another pin connection, at a level which corresponds with the centre of pressure on the gate at high water of spring tides, and at a point about ·28 of the length of the gate measured from the meeting face of the mitre post. A bracket is riveted to the upper side of the horizontal strut near the inner end thereof in which bracket two bolts, fixed at a distance of 9 inches apart, form connections for the eyes of the two ends of a 5-inch steel rope. This rope is carried from these eyes in each direction to two guide pulleys, of which the inner pulley is secured at the angle formed by the arched top or soffit of the trunk and the outer or lock side of the vertical shaft; and the outer pulley at the angle formed by the same soffit of the trunk and a chase sunk in the side of the gate recess. From the inner pulley the rope is carried up directly to the grooved barrel of the winch, is wound round that grooved barrel, and therefrom is carried in a horizontal direction in a chase formed for its housing in the lock wall to a union screw (for strain adjustment) from which it is continued over a third guide pulley and down the vertical chase which has been already described. Each of the systems of wire ropes, therefore, forms an endless system of haulage of which a part is always coiled round the grooved barrel of the winch, while the remainder of the system travels in either direction; according as the motion of the winch is from left to right or from right to left; and thereby actuates the strut by which the gate is controlled either in an inward or an outward course as may be desired for the opening or closing of the gate.

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* The hydraulic gear by which the Armstrong capstans which have been in use for many years at locks and entrances for the purposes of wharfing ships through the locks and moving them in the entrance, are fitted with reversing gear in the majority of instances.

The special advantages which are claimed for this form of gate machine are obvious. (1) The leaf of each gate is opened and closed by one and the same machine. (2) The strut by which the leaf of each gate is moved is secured to that leaf at the best possible point, that is to say, approximately at the centre of the pressure upon the gate when in motion at spring tides. (3) The motive power and the working parts of the machinery are all above water level, and access thereto can be obtained at any time and without difficulty. On the other hand, the rails, the crosshead which slides thereon, the strut with its pin connections, and the connections between the steel ropes and the bracket on each strut, as well as the two lower guide sheaves for the ropes, are always under the level of the water even at times of low water of spring tides; consequently the repairs and renewals of these details, can only be effected in one of two ways (*a*) by the pumping out of the waters from the vertical shaft and the trunk, and (*b*) by means of a diver working in the trunk and under water. In order to render the first of these two methods practicable, the back of each leaf of the gates has been fitted with two vertical fenders which are fixed in such positions and have such projections that they, together with a cross fender by which the feet of the vertical fenders are connected, come into direct contact with the face of the gate recess when the gate is hove fully back into that recess, and so form a limpet-like panel which bears against the masonry of the gate recess. It is claimed that this panel provides and will provide a watertight dam which renders it possible to pump the shaft and the trunk dry, and thus to provide access to the submarine parts of each gate machine for examination and for repair. Time alone will prove what the permanent value of this device is, but the method has already been successfully tested in practice in connection with the machines at the entrance to the King George Dock.

The machinery thus described was patented by Mr. T. L. Norfolk, of Hull, and the whole of these and of the other hydraulic machines connected with the lock, were manufactured by the Hydraulic Engineering Company, Limited, of Chester, to whose courtesy we are indebted for the working drawings from which Figs. 18, 19, and 20, in which the gate machines are illustrated, were derived.

In addition to the gate machines by which the lock gates were operated, similar machines, though of somewhat smaller dimensions, were supplied by the Hydraulic Engineering Company, Limited, of Chester, for the working of the gates for the two dry docks, which were built in connection with the Joint Dock, and the entrances of which are respectively 72 feet and 66 feet in width; and at the

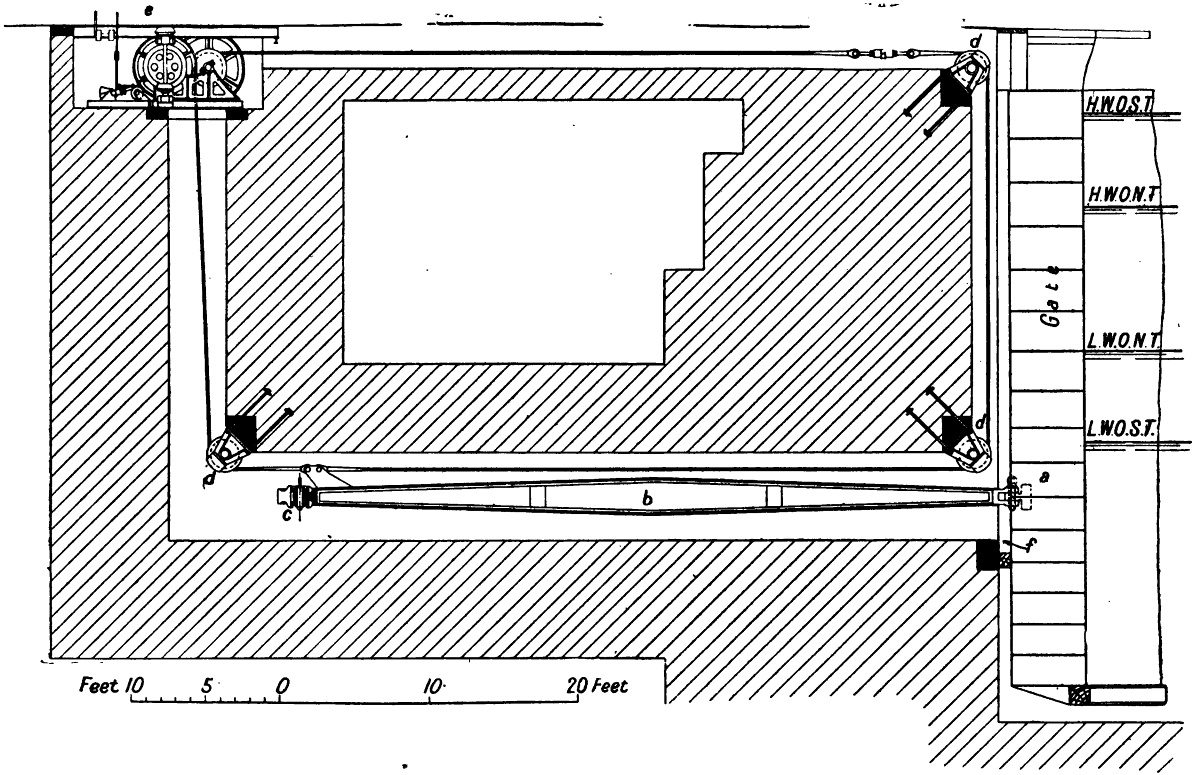

FIG. 18. GATE MACHINES, KING GEORGE DOCK, HULL.

Sectional elevation of " Norfolk " hydraulic machine.

a Connection with gate. *b* Steel strut. *c* Crosshead.
d d Guide pulleys. *e* Hydraulic winch. *f* Limpet or panel dam.

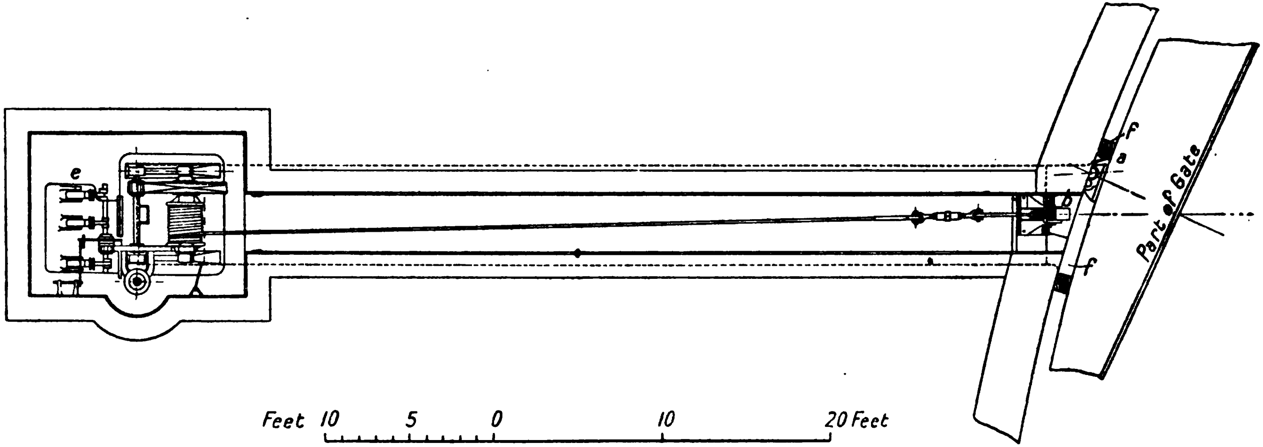

FIG. 20. GATE MACHINES, KING GEORGE DOCK, HULL.

Surface plan of "Norfolk" hydraulic machine.

time of writing, the makers have in hand the construction of further machines of the same type for the North Basin entrances which the North-Eastern Railway Company are building at Hartlepool.

Before discussing briefly the questions relating to the use of chains or ropes as connections between the gate machine and the gate which is to be worked thereby, a brief description of an installation of hydraulic gate machines ("hydraulic" in the sense that they are actuated by water power) of a different type altogether may be interposed at this point with some advantage, as the machines in question are peculiarly suitable for circumstances such as those under which they were first introduced, and as the type is but little known. The machines were installed at the several pairs of locks which were built in connection with the reconstruction of the River Weaver Navigation* between the years 1873 and 1882. In two of the cases which are in point the pairs of locks consisted of a so-called "large lock" which was 42 feet 8 inches in width, and a "small lock" to which reference has already been made in these pages. Each lock was fitted with three pairs of gates, intermediate gates being constructed between the usual upper and lower gates. There were therefore six leaves and twelve gate machines in each large lock. The Weaver drains an area of 489 square miles, parts of which consist of hill country in Derbyshire and of mountainous districts in North Wales, the remainder of the watershed being composed of the level plains which characterize the agricultural districts of Cheshire. The supply of water is therefore perennial, and for the greater part of the year large quantities of water are running to waste, while the fall at each set of locks varies from 8 feet to 8 feet 6 inches. Advantage was taken of these circumstances, and in the building of the lock walls two lines of cast iron pipes, which in one case formed a head race for supply, and in the other a tail race for discharge, were laid on each side of the large lock. Turbines of the "Schiele" pattern, in which the head water is led through outer vanes to the periphery of the wheel and is discharged through upper and lower openings in the centre, were fixed in pits, two of which were built in connection with each leaf of the gates, one for the opening and the other for the closing turbine, and were connected with the head race by means of branch pipes which were controlled by sluice

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* See note at foot of page 16.

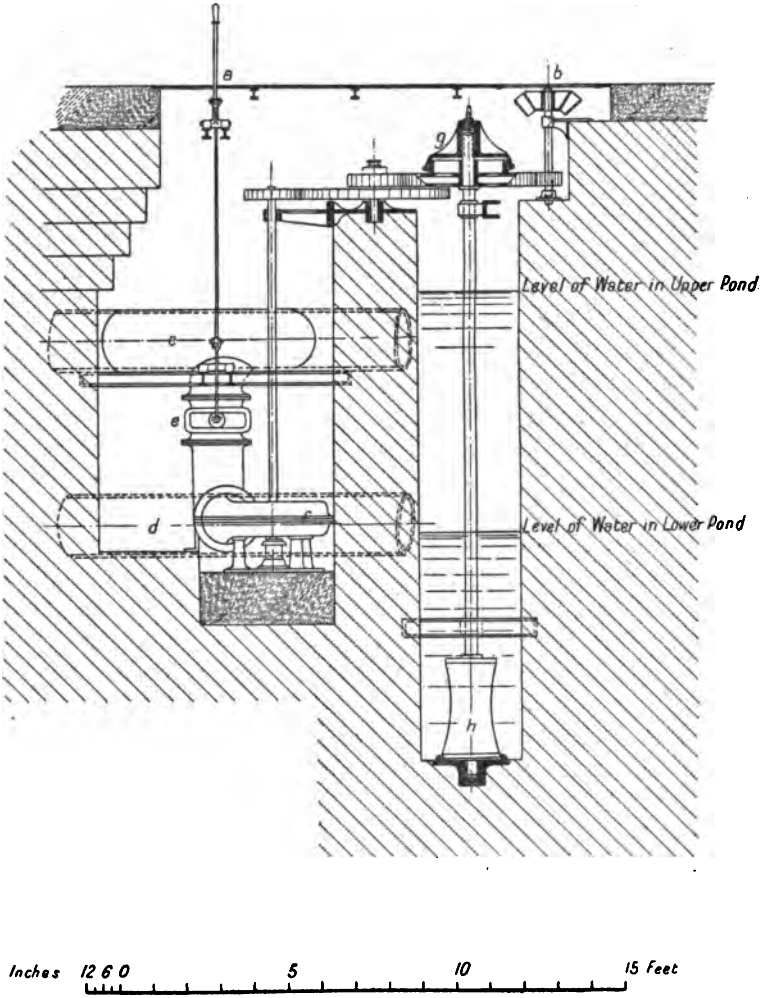

FIG. 21. GATE MACHINES, WEAVER NAVIGATION.

Sectional elevation of turbine machines.

a Operating lever. *b* Hand gear. *c* Headrace.
d Tailrace. *e* Sluice valve. *f* Turbine.
g Friction gear. *h* Chain barrel.

valves. The vertical shaft at the lower end of which the turbine is keyed, was in each case carried up above the highest water level and was connected through spur gearing with a second vertical shaft. This shaft was fitted at the upper end with friction cones, and at the lower end with a vertical chain barrel, the level of the centre of which corresponded with that of the centre of the maximum pressure upon the gate, i.e. the pressure when the gate was moved at the time of the highest level of the water. Each chain, therefore, whether for opening or for closing, led directly and in a traight line from the barrel to its attachment on the gate. The machines were thus reduced to the ultimate limits of simplicity and of directness of action, with the result that they have been in daily operation for over forty years, have given no trouble, their average annual cost for maintenance has been trifling, while their working expenses have been covered by the expenditure which has been incurred for the oil used for lubrication, plus that for the cotton waste which, in spare moments, the lock tenders have used for their cleaning of the gear.

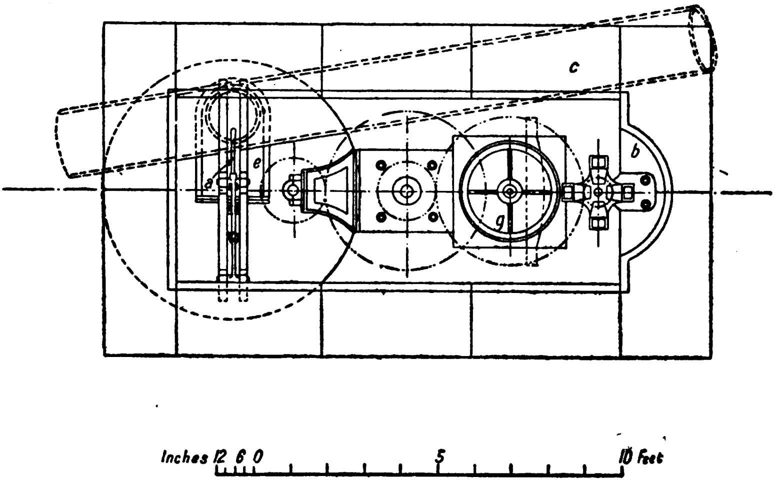

FIG. 22. GATE MACHINES, WEAVER NAVIGATION.

Plan of turbine machines.

a Operating lever.
b Hand gear.
c Headrace.
e Sluice valve.
g Friction gear.

The design and general arrangement of the turbine machines in use on the Weaver Navigation are shown in Figs. 21 and 22.

The Weaver locks were built for small coasting vessels and for large steam barges, and experience of their working seems to have shown that the large locks have furnished an approximate gauge by which the capacity of a dock entrance, equipped with gate machines which involve the use of chains, may be estimated in the future. In much wider and deeper entrances, as hereinbefore hinted, two lines of development have come into conflict, viz. the development of the ship and the development of the gate machine. It is undeniable that the entrance with its equipment of gates and gate machines exist for the ship and not the ship for the entrance, and it is but to be expected that the gates and the machines which operate them would have to be adapted to the requirements of the vessel, however unreasonable these might appear to be. The evolution of the chainless machine has followed as a matter of necessity, and must be counted as being a sound development, a possible alternative being available in machines of the type employed in the lock entrance to the King George Dock at Hull.

This principle or some alternative thereto should henceforth be accepted by the engineer and the designer and should be acted upon. And this in despite of the fact that for years past shipbuilders, urged by ship-owners, have laboured to reduce to an exact science the art of building steamers which will combine a maximum capacity for carrying cargo (on which the shipowner will be paid freight) with a minimum of registered tonnage (on which he will pay ship's dues) so that the shipowner may obtain all the advantages which he can command in the dock, harbour, or waterway in which he finds safe and comfortable accommodation, at the least possible cost to himself, which obviously means, with the lowest possible remuneration to the owners of the dock, navigation, or canal.

With regard to the questions which were raised in a previous page as to the relative advantages of wrought iron chains and of steel wire ropes for the gate machines of which they form part, perhaps the safest conclusion will be that embodied in the immortal judgment of Sir Roger de Coverley, that "there is much to be said on both sides." The chains have a long and useful history behind them, they are more flexible than the ropes, and are more easily repaired; but the power required for their operation is excessive and the loss through wear and tear to which they and the sheaves by which they are carried are subject, is a serious element in the working expenses of the machines. The wire ropes are more modern and therefore more fashionable; and if it be remembered that for gate machine use particularly, a wire rope should not in any case be turned round a barrel or a sheave which has a diameter less than thirty-two times that of the rope (forty times would be better), they have a value peculiar to themselves. It is, however, not every rigger who can splice a wire rope in such a way that he leaves both the strength and the pliability of the rope on which he has operated unimpaired; consequently it usually occurs that in the case of a rope which forms part of a gate machine one breakage means that the rope must be discarded and a new rope substituted for it. Generally, for the working of gates in dry docks, etc., in which frequent movement is not required, ropes may have the balance of advantage; but in locks where the gates are opened and closed many times a day in comparing old-fashioned chains with new-fashioned ropes it may be said as in the case of the comparison between old and new wines that "the old is better."

In concluding the observations thus offered in respect of chain connections between gate machines and the gates which they control, one further consideration should be placed on record. Reference has already been made to the fact that in the process of the evolution of the cargo steamer, the midship section of that useful craft has approached more and more to rectangular form. In the true up-to-date vessel, any trifling amount of rounding off at the bilges has been in effect restored to angularity by the projection of a bilge keel, or rolling chock, from the centre of the bilge curve at each side of the ship. The bilge keels are usually formed of bulb plates which are tacked on to the sides of the ship by means of a single line of steel angles, or in the large steamers by means of double lines of angles or of a line of tees. The only central keel with which a steamer of modern build is furnished exists in the form of a continuous plate by means of which the joint on the midship line (due to the meeting on that line of the lower strakes of the plating of the ship) is covered. With a deep drafted steamer carrying for a great part of her length such a box-shaped section as that described, through a dock entrance or into a lock, the space, which is left for clearance is not very much more than sufficient, even if all be well with the ship. But it frequently occurs that all is not well with the ship so far as her bilge keels are concerned, and that at some stage in her voyage and from some cause or another, one of these keels has received damage ; has been sprung at one of the joints in the bulb plates ; or that the bulb plates themselves have been torn from their attachment to the ship's hull so that their ends hang down below the level of the bottom of the ship in such manner that in their pendant positions they catch the forebays, scrape over the sills, and foul everything which they find in their destructive way. Little perspicacity is required to appreciate the effect of such an intrusion upon the chains of the dock gates, or to recognize the fact that the modern methods of building cargo steamers are not such as to encourage the use of gate machines which are connected with their gates by means of the system of chains or ropes which held sway for so long a time.

CHAPTER IV

GATE MACHINES IN THE PANAMA CANAL: TOGETHER WITH A DIVERSION INTO THE SUBJECT OF GATE ROLLERS

It was suggested in the preceding chapter that from the middle of the nineteenth century, when the use of hydraulic gate machines was established as a corollary of Mr. W. G. Armstrong's invention of the hydraulic accumulator, to the close of that century, hydraulic power held the field so far as the operation of machines for opening and closing dock gates were concerned; and the suggestion will be accepted by all those who remember, or have made themselves acquainted with, the engineering history of these fifty years. But the hegemony of the hydraulic machine was not permitted to pass without challenge, a challenge which grew more insistent as the half-century drew to its close. Everyone knows who the new Richmond in the field was, or if there be one from whom the knowledge has been hidden, the man in the street will tell him strange tales about electricity and the electric current. Early in the century Professor Michael Faraday's discoveries prepared the way, and his work was followed up in many directions by philosophers, scientists, and mechanics. One result of their conjoined efforts is that the correlation of electric generation, transmission, and consumption in a system composed of a dynamo at one end of a conductor, and a motor at the other end, has been found to be a reasonably efficient method of working gate machines in a dock entrance, and electric machines have become the fashion of the twentieth century.

If a conclusion which has been arrived at and which will be found in the closing chapter of this work may be anticipated here, it may be alleged that the fact is that there is a flexibility about electric machinery which hydraulic machines lack. The electric current is more easily distributed than is the case in any other medium for the transmission of power, in addition to which, electricity has a special attraction for engineering men in charge of public works who are growing in years and in weight avoirdupois, who like regular habits, and who, when they have persuaded Corporations and Boards to supersede hydraulic machinery by electric gear, feel that they can sleep in their beds on dark winter nights, even though the thermometer falls to a temperature equal to zero on the Fahrenheit scale. On the other hand, the loss of density which is inevitable in the distribution of electric current is very serious, and the further loss of energy in electric gate machines consequent upon the great difference in velocity of movement between (*a*) the motor which drives the gate machine, and (*b*) the gate which is driven by it. This excessive difference in speed of movement naturally involves the interposition of so great a train of speed reduction gearing between the motor and the gate machine that it becomes a grave element in the consideration of each case, whether regarded from the point of view of first cost, of maintenance, or of working expenses. Partly for these reasons and partly from the innate conservatism which is at once the strength and the weakness of the British mind, electric gate machines have obtained no standing in the British Isles, while on the Continent of Europe and in America they have largely superseded the hydraulic machines in modern works. Two notable examples of American practice, both of which are on a great scale, and which may be said to embody the last word in each of two different lines of electric machinery for the working of gates will, therefore, be presented in this and in the succeeding chapter.

For the reasons given, and because the waterways, of which the machinery in question forms part of each equipment, are of such outstanding importance and of such supreme value as avenues of transportation for the world's commerce, because they have cost such vast sums of money, and have been able to command the best of contemporary skill and experience in all branches of engineering practice, it is thought that the two examples will be sufficiently representative to meet the purposes of this work; multiplication of examples and of illustrations would only show diversity of detail, which in many cases would only be of value as beacons indicative of points which should be avoided.

Of the two great waterways, the first is the Panama Canal, by the construction of which a maritime highway has been formed across the isthmus which furnishes the slender link between the North and South American Continents, and through the mountains, of which the backbone of the two great Continents is composed, and which extend in one mighty line, rugged but continuous, from Alaska in the north to the Straits of Magellan in the south. Through the way which has been thus opened the largest steamships afloat can now pass between the oceans which form the main highways of the world, can reach the Pacific from the Atlantic, or vice versa, and so can not only circumnavigate the globe with convenience and safety, but can for the greater part accomplish the journey on or near the Equatorial line.

The second of the waterways in question is the system composed of the Erie, Oswego, and Champlain Canals, in the State of New York. That waterway is familiarly and characteristically described in the State by which it is owned and which it is to serve as "the hundred and one million dollars canal." The derivation of the title arose out of action taken by the State Legislature in 1903, when the great sum named was voted for the reconstruction, on improved and greatly enlarged lines, of the system formed of the old canals which were opened in 1825, and through which water communication was afforded between the Atlantic Ocean, via the Hudson River, and the great inland seas which lie between the Dominion of Canada and the United States.

Parts of the Erie Canal system have already been completed and are at work, in which connection some special interest was attached to the opening of the canals in the State of New York in the spring of 1915. Advantage was taken of the occasion of this opening for the purpose of the inauguration of a short but important section of the New Barge Canal, which is situated at the eastern end of the Erie branch of the waterway and which has superseded a length of the old canal which was well known on account of the numerous locks which lay in proximity to each other upon it, and which were required to overcome the considerable fall between the canalized Mohawk River (which now forms part of the new waterway) and the Hudson River at Waterford.

The new section comprises what is claimed to be the greatest flight of high lift locks in the world, a flight which consists of five locks all situated within a length of one and a half miles, and of which the combined lift is 169 feet; or an average of nearly 34 feet in each lock. As a matter of fact, the lifts of the several locks vary from 32 feet 6 inches to 34 feet 6 inches. The inaugural ceremony was graced by the presence of a number of dignitaries, including the Governor of New York State. The sluices for the filling and emptying of the various locks were operated with much more than ordinary care. In only one case were the culverts on both sides of any lock employed concurrently. This was at Lock No. 5, and there the lockage was performed in six minutes, counting from the time at which the closing of the lower gates was begun to that at which the opening of the lower gates was completed. It was found that even on this special and official trip, when caution rather than enterprise governed the operations, the boats made the passage of the new Waterford series of locks in a few minutes under an hour, whereas the ordinary passage by the old canal and its numerous locks occupied three and a half hours; so that this practical experiment was justly regarded as presenting a favourable augury for the success of the canal as a great engineering effort.

To revert to the great trans-isthmian waterway, in days now for ever past, on the Atlantic side of the Isthmus of Panama, in the valley of the Rio Chagres and about 3½ miles from the coast line, there lay a conglomeration of huts, shacks, and hovels which was known as the village of Gatun. That village disappeared from the sight of men years ago, but its memory has been kept alive by the most amazing series of lock entrances which has ever been built or thought of on this earth, and which is to be known for all time as the Gatun Locks. At Gatun the locks form a "Neptune's staircase," a double staircase in this instance, as laterally the locks were built in pairs, while longitudinally they were built in a series of three steps of titanic size. There are, therefore, six locks in all, and as each lock is fitted with a pair of intermediate gates, there are (irrespective of the guard gates) fourteen pairs of gates in the double staircase, with twenty-eight leaves, and the same number of gate machines, each machine being capable of both opening and closing the leaf which it controls. These intensely modern gate machines furnish a most interesting example of unconscious reversion, as they are, in fact, a development of the quadrant type of machine described and illustrated in Chapter III, but which also, as might be expected from the great difference in dimensions, include certain well-marked features of departure.

The gate machines employed at the Gatun Locks and at the locks which correspond thereto on the Pacific side of the divide (the latter were constructed at two separate sites 1½ miles apart, the one—which has the usual single step only—having been built at Pedro Miguel, and the other, which has two steps, at Miraflores) were designed and patented by an American engineer who was formerly in the employment of the Isthmian Canal Commission, have been worked to a considerable extent with such success that there seems to be no reason to doubt that in the future the machines will prove to be as reliable as they have been in the past of their short history.

The "Schildhauer" electric gate machines, to designate them by the name of their patentee, are shown in plan on Figs. 23 and 24* and in section on Figs. 25 and 26. It will be seen that the salient feature of the machine is a horizontal spur wheel which is formed of cast steel and is furnished with teeth for rather more than half of its periphery. The spur wheel was in each case cast in two halves, which are securely bolted together; it swings in both directions on a vertical stud which forms the centre of the wheel and which is supported in a footstep, which in its turn is solidly bolted down to the concrete work in the bottom of the pit constructed for the reception of the

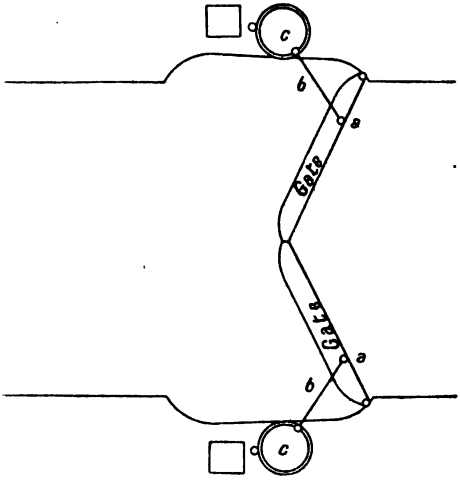

Fig. 23. Gate Machines, Panama Canal.

Diagram showing relative positions of "Schildhauer" electric machines and gates.

a Connection with gate.
b Connecting rod.
c Horizontal spur wheel.

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* These figures were prepared from photo-prints of the working drawings, which through the courtesy and kindness of General George W. Goethals, U.S.A., were furnished for the purpose of this manual. General (then Colonel) Goethals was Chief Engineer and Chairman of the Isthmian Canal during the greater part of the time when the Panama Canal was under construction, and now occupies the distinguished and responsible position of Governor of the Canal Zone.

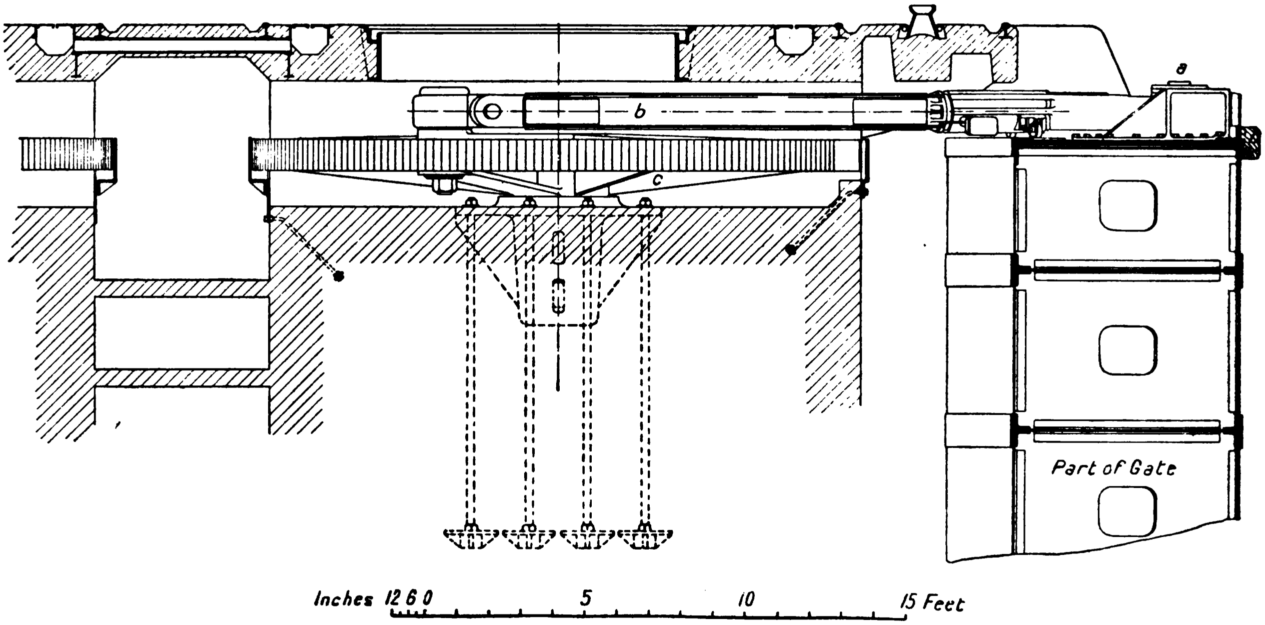

FIG. 25. GATE MACHINES, PANAMA CANAL.

Sectional elevation of "Schildhauer" electric machine.

a Connection with gate. *b* Connecting rod. *c* Horizontal spur wheel.

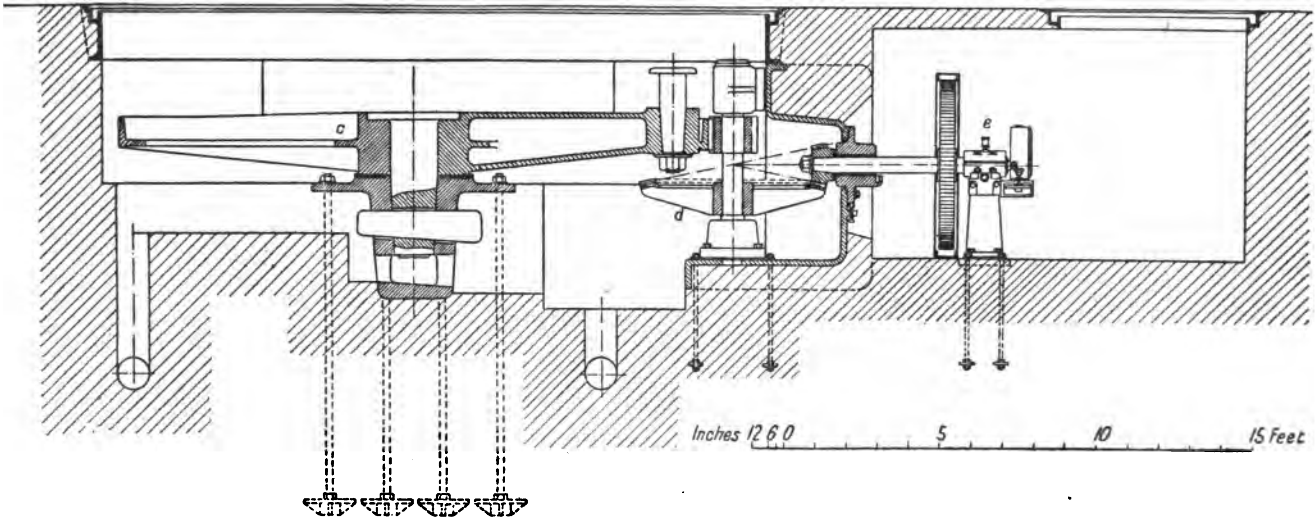

FIG. 26. GATE MACHINES, PANAMA CANAL.

Section of "Schildhauer" electric machine.

c Horizontal spur wheel. *d.* Bevelled gearing. *e* Spur gearing.

machine, a pit which opens at the outer end to the gate recess. A steel pinion keyed on to a vertical shaft (to which shaft a bevel wheel is also keyed) engages in the teeth of the spur wheel and so moves the wheel backwards or forwards, so far as the limits of the peripheral teeth permit. The vertical shaft revolves in a footstep below and in an overhead bearing at its upper end, and the bevel wheel thereon is driven by means of a bevel pinion which is keyed on the outer end of an intermediate horizontal shaft. This horizontal shaft is in turn driven by a vertical spur wheel, into which a pinion on the spindle of the electric motor works. The gear between the motors and the horizontal spur wheel presents a somewhat formidable appearance, but this is unavoidable as the motor runs at 500 r.p.m., and as the reduction affected by (*a*) the two sets of spur gearing; (*b*) the bevel gear; and (*c*) the difference in the proportions of the horizontal spur wheel and the pinion which swings that wheel to and fro, is in the ratio of 1 to 1800. The speed on the pitchline of the spur wheel when running without load would, therefore, be at the rate of about 3·6 minutes for one complete revolution, if that revolution could be effected.

This example is of itself a sufficient commentary on the observations offered in the beginning of this chapter, and which relate to some of the difficulties which are inherent in the employment of electric current for the operation of gate machines.

For the connection of the gate machine with the gate a second stud or crank pin was fixed in one of the radial arms of the wheel (which was formed of a special box-section for the reception of this pin) at a distance of 8 feet 3·53 inches from the centre of the wheel, and a stud corresponding with the stud in the radial arm was fixed in a special steel box which was provided therefor, and which was secured to the upper side of the upper horizontal beam or rib of the steel-built gate which the machine operates. The distance of the gate stud from the centre of the heel post of the gate is 17 feet, and the distance from the line of the back of the gate 1 foot 1 inch. The length of the back of the gate from the centre of the heel post to the bearing on the mitre post is 69 feet 11 inches, so that the point from which each leaf is worked is fixed at less than one-fourth of the total length of the leaf measured from the centre at the heel post end of the leaf. The crank pin on the wheel and the pin which forms the attachment of the gear to the gate are coupled together by means of a connecting rod with a constant length (except when affected by shock) of 24 feet 3·53 inches. This connecting rod moves in a horizontal plane and is fitted with a triple spring at the outer or gate end in order to take up any shock which may arise in the working of the gate, and to relieve the gear from any sudden and dangerous strain. Two small supporting wheels were also fitted on the underside of the outer end of the connecting rod. These small wheels travel on a segmental roller path which is secured to the top of the gate and serves to steady the outer end of the connecting rod as it propels the gate outwards to the sill or draws it back into the recess as may be required. The angle of the swing of the gate measured between the outer position at the sill, and the inner position in the recess, is 63° 26′ 6″, and the angle of the swing of the spur wheel measured between the same positions of the gates, is 196° 45′ 30″. The radius in the one case is 17 feet and in the other is 8·29 feet; the respective lengths of the swing of the two pins as measured by the length of the arc which each traverses in passing from the one position to the other are therefore 18·82 feet in the case of the gate and 28·48 feet in that of the spur wheel.

The average level of the water in Gatun Lake—as the sheet of water by which the unsavoury group of rural residences in Gatun village were submerged has been named—is intended to be maintained generally at 85 feet above the mean level of the sea. In overcoming this difference of level three lock stages were employed, as we have already seen, so that each stage represents a mean difference of 28′ 4″, which will sometimes be increased and sometimes be diminished according as the discharge of the Chagres River varies, or as the feeble and fluctuating tides in the Caribbean Sea ebb and flow. The depth on the sill is 45 feet in each case, and if 8 inches be assumed (for the sake of round figures) for the bearing of the sill of the gate on the sill of the lock it will appear that the area of resistance to movement presented by the immersed surface of each leaf is 69·91 (28·33+45+·67)=5173 square feet. If this figure be co-ordinated with that relating to the position in each leaf of the pin which in each case forms the attachment between the gate machine to the gate, an accurate idea of the work which these electric gate machines are called upon to perform on each occasion when the inertia has to be overcome and the leaves are to be started from rest, can be arrived at. The whole machine system is worthy of the study of any thoughtful engineering enquirer, while the boldness of the scheme, and the thoroughness with which the design for the gate machines was worked out will certainly encourage and give assurance to the gate machine designers of the future. As will appear in a subsequent chapter the design has, so far as an outsider can judge, already influenced, in no small degree, the type of machine chosen for the operation of the gates in another large lock which has recently been built on the Mississippi River.

In the gates in the locks in the Panama Canal each leaf is kept as nearly afloat as is consistent with safety, so that there is but little dead weight to be moved. This is the universal modern practice in the working of box-built gates, i.e. gates with two skins divided and supported by horizontal or vertical framing, or by a combination of the two.

In such gates questions as to whether end rollers (as they are called, they are really wheels and axles with adjustable spear posts for the regulation of the load upon the rollers) should or should not be fitted at the outer end of each leaf as a safeguard against injury and for the purpose of steadying the leaf in its travel, either in or out, do not arise as they sometimes do arise in the case of non-floating gates. In the consideration of the problem as to whether rollers should or should not be attached, the following points may be regarded as axiomatic so far as the strongest case for the rollers, that of heavy gates built of greenheart timber is concerned. First, rollers and their roller paths will add sensibly (*a*) to the first cost of the gates; (*b*) to the working expenses of the gates, and (*c*) to the charges for the maintenance of the gates and of their machines. Secondly, the rollers will add to the risk of shock at the mitre post end of the gate in the event of an obstruction finding a lodging place on the roller path therefor, or of silt or other material caking against and on the path. Thirdly, the gates can be worked satisfactorily and with perfect safety without rollers if they be built with diagonal bracing in both directions, i.e. with a diagonal strut between the foot of the heel post and the head of the mitre post and with a diagonal tie, capable of being adjusted, between the foot of the mitre post and the head of the heel post.

It may be objected that the latter statement is not axiomatic as the proposition is not self-evident. The answer to the objection is that if the matter be put to the proof the proposition will become self-evident to any competent observer. If this statement seems to bear with it an unduly and unpleasantly dogmatic sound or tone, the *apologia* therefor, fittingly offered, lies in the fact that it is based on the extended experience of men whose business it has been not only to build large gates, but also to operate and to maintain them.

CHAPTER V

ELECTRIC GATE MACHINES IN THE ERIE CANAL, AND GATE MACHINES IN THE LOCK AT THE KEOKUK DAM ON THE MISSISSIPPI RIVER

LEAVING now the Tropics and the Panama Canal for the time being and turning to the electric gate machines on the new Erie Canal and its branches, to which canal brief allusion was made in the preceding chapter, it will appear that the gate machines on that great system are, as befits the more modest dimensions of the locks on an inland barge canal, of simpler and less expensive design than those on the Panama Canal. Their general design and the details of their construction are shown in Figs. 27 and 28. The principle relied upon in the operation of the machines has some similarity to that employed in the more recent hydraulic machines which have already been described, although a revolving pinion and a rack take the place of the ram and connecting rod. The motor which drives each machine is contained in a steel cabinet which stands above the level of the quay of the lock, while the gate machine proper is fixed in a pit below the same level. This pit is 12 feet 7 inches in length and is 4 feet wide at the face of the gate recess, 8 feet 6 inches wide at the back, and 3 feet in depth. The motor is connected with the pinion which operates the rack by means of three sets of spur gear and one set of bevelled gear, the speed reduction effected by the whole gear being from 215 to 1.* The pinion revolves on a vertical shaft, and the rack with which the teeth of the pinion engage is formed of cast steel, and is attached to a built up mild steel boom or spar. The boom has a length of 13 feet, and is at the outer or gate end pivoted to a vertical spindle which is 5 inches in diameter and is secured between the webs of the upper beam of each gate (that particular beam being of box form in section), between which the outer part of the boom moves in accordance with the travel of the gate, whether

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* 215 revolutions of motor shaft to 1 revolution of operating pinion, which has a pitch diameter of 12 inches.

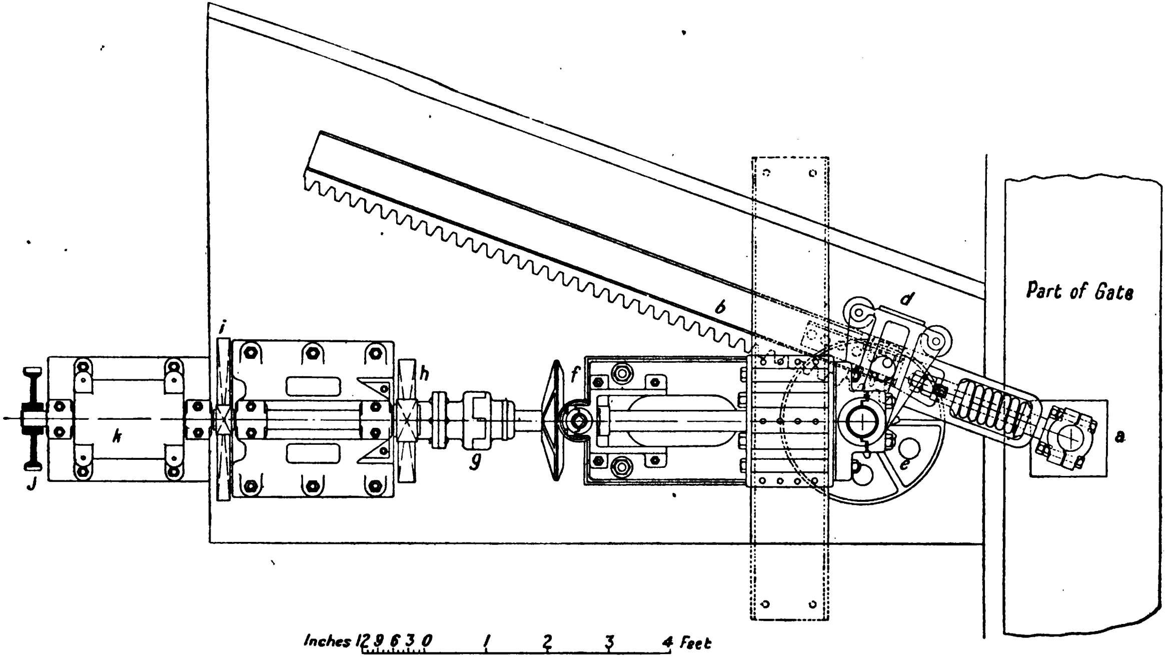

FIG. 27. GATE MACHINES ON THE ERIE CANAL.

Plan of electric pinion and rack machine.

a Connection with gate.
b Boom and rack.
d Guide for boom.
e Bevelled gearing.
f Hand gearing.
g Clutch for hand gear.
h Spur gearing.
i Spur gearing.
j Spur gearing.
k Electric motor.

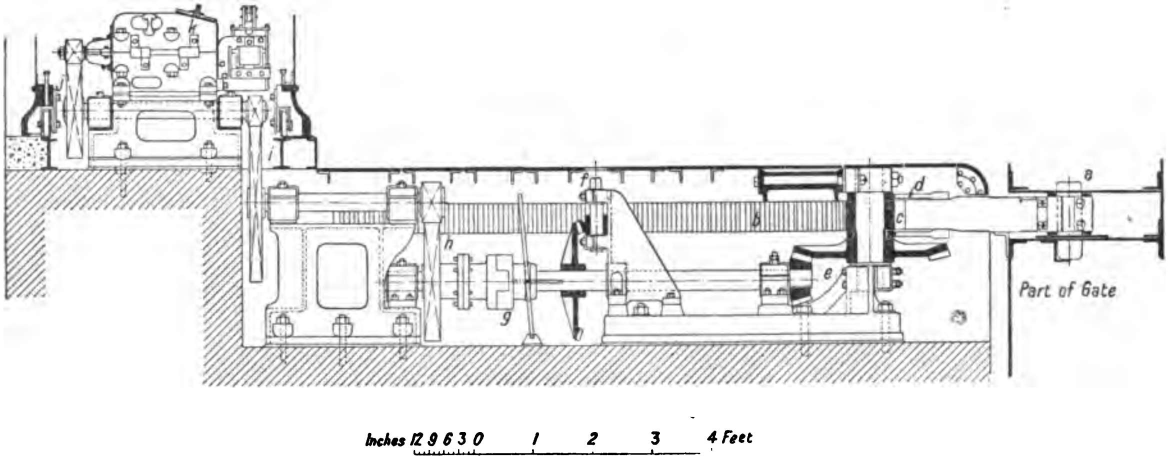

FIG. 28. GATE MACHINES ON THE ERIE CANAL.

Elevation of electric pinion and rack machine.

a Connection with gate.
b Boom and rack.
c Pinion for rack.
d Guide for boom.
e Bevelled gearing.
f Hand gear.
g Clutch for hand gear.
h Spur gearing.
i Spur gearing.
j Spur gearing.
k Electric motor.

outward or inward. At the outer end of the rack the boom is supported by means of a roller guide, and a special slotted guide is provided for the boom at the point of contact between the rack and the pinion. The boom terminates at the outer end in a substantial steel bar which is fitted with a spring thrust bearing for the avoidance of shock. The radius of the arc which the vertical spindle (which forms the attachment between the boom and the gate) describes as the gate moves in and out, is 8 feet 4½ inches and the angle is 70 degrees. The length of the travel of the gate measured on the arc is therefore slightly over 10 feet.

The machines generally are not unlike those which were fitted to the gates in the locks at each end of the original Kiel Canal (subsequently named the Kaiser Wilhelm Canal), which extends from Brunsbüttel on the Elbe to Kiel on the shores of the Baltic Sea. The Kaiser Wilhelm Canal has been widened and deepened by the German Government during the last few years, and locks of increased size have been constructed at each end of the enlarged waterway. The widened and deepened canal was opened for traffic in 1914, but events moved rapidly after these opening ceremonies were over, and information as to the machines by which the gates in these larger locks are operated was not available under the circumstances which existed in Europe at the time when this chapter was written.

Reverting then once again to the Erie Canal system and to the locks thereon, the pits in which the gate machines are housed, are covered by steel chequered plates, so that except for the motor cabinets (which stand well back from the coping) there is no obstruction on the quay. The " cabinets " were very carefully constructed and finished, they are mounted on wheels and can, therefore, be rolled entirely clear of the machinery, leaving the various parts exposed for cleaning, oiling, repairing, and painting. This is a somewhat striking feature in these machines, which are throughout of a very practical and useful type. The principal drawback in the design of the machines is undoubtedly that which has already been described as inherent in the employment of electric machinery for working gates ; that is to say, the necessity for the employment of reduction gear to an extent which renders the proportion of the cost of the machine which is due to that gear a serious element in the capital charges for the plant, and also renders the loss caused by the interposition of the gear and the driving thereof a sensible item in the working expenses of the operating machinery.

The locks on the main line of the Erie Canal, which extends from Troy on the Hudson River to Buffalo on Lake Erie, as well as on the branches which connect that main line with Lake Ontario and Lake Champlain (and which are known respectively as the Oswego Canal and the Champlain Canal) vary in length from 338 feet to 343 feet between quoins and are 45 feet wide, with a minimum depth of 12 feet on their sills. The timber-built barges at present in use on the canal and its branches consist (1) of steamers 98 feet in length by 18 feet in beam, and (2) of dumb barges or "consorts," as they are termed, which are of similar dimensions and which for the greater part are pushed onward (not towed) by the steamers, though it is not unusual to see a steamer pushing one consort and at the same time towing two others in tandem behind. Generally, however, a steamer and consort is navigated as a single unit which carries a load of 480 tons, 230 tons of the load being borne in the steamer and 250 tons in the consort.

The dimensions of the steel-built barges proposed to be employed for the traffic on the enlarged canal system have not yet been definitely determined. It has been suggested that they should vary from steamers and consorts with a length of 155 feet and a beam of 35 feet in each case, and having a joint capacity of about 2500 tons (divided between steamer and consort into 1200 tons for the one and 1300 tons for the other), to single barges which will be self-propelled, will be 310 feet long by 40 feet beam, and will carry about 2400 tons each. One practical advantage in the use of the steamer and consort unit with beam limited to 35 feet would be that such a unit would be able to pass another and similar unit at the narrowest parts of the canal.

The gates in the Erie Canal locks are built of steel and have single skins only; they have, therefore, no power of flotation, and none of them are fitted with rollers. The whole canal system, and particularly the locks, the gates therein, and the gate machinery therefor, furnish a striking example of modern engineering design and construction for the purposes of a waterway of which the dimensions are intermediate between those of the giant locks and entrances of our own times, and those of the comparatively pigmy locks of older days.

Another recent and interesting example of large lock construction in the United States originated in the fact that in the year 1905 an Act of Congress was obtained under the powers of which the establishment of what is claimed to be " the largest hydro-electric power plant in the world " was authorized at a site on the Mississippi River at the city of Keokuk, on the easterly border of the State of Iowa, an integral part of the scheme being the building of a great dam across the course of the Mississippi for the provision of the water power for the operation of turbines and for the generation of electric current thereby. The Federal Government of the Republic approved of the scheme and consented to its promotion, but made the condition that the Company which proposed to establish the works should, in connection with the dam and at their own cost, undertake to construct in the great river a lock and a dry dock which should both become the property of the Federal Government on the completion of the works.

The works were commenced in 1910 and (including the dam which is 4649 feet in length) were completed in July, 1913. The enterprise itself was of no ordinary character; the boldness of the design of the works, the brevity of the time required for their successful completion, and the manner in which they were carried out, gave the undertaking a distinct educational value for engineering students in the United Kingdom and elsewhere; and it is fortunate for these that an excellent and fully illustrated description of the whole scheme was published in 1913 by the proprietors of " Engineering " in Vol. XCVI of that well-known journal.

It is with the lock (which was duly constructed in accordance with the agreement with the Federal Government) that we are concerned here, and particularly concerned with the machines by which the lower gates of the lock are operated. These machines are similar in general design to the gate machines which were constructed under the patent of Mr. Schildhauer for the Isthmian Canal Commission; but apart from that similarity a special interest attaches itself to the design of the gate machines for the lock in the Keokuk Dam.

The lock is 400 feet in length and is 110 feet in width, so that so far as width is concerned it ranks amongst the largest locks of the day, being equal in width to the Panama Canal locks. At the upper end of the lock the gates, which are in duplicate (they comprise (1) a guard gate and (2) a working gate), are constructed in the form of semi-pontoons and are placed in recesses which were constructed for their reception on lines at right angles to the lock. These gates are simply steel boxes or chambers (with super screens thereon) which, for opening purposes, are submerged by the admission of water into the chambers, and are raised again when required to be closed by compressed air which is forced into the chambers and by means of which the submerging water is driven out and the buoyancy of the whole structure is restored. The dry dock which adjoins the lock is fitted with one gate precisely similar to the two upper gates in the lock, so that there are in all three gates in the lock and dock which are identical in form and in dimensions and are therefore interchangeable. It is not necessary at this point to deal further with this new departure in lock gate construction, except so far as to suggest that the students to whom reference has been made should watch the working of these gates and should take advantage of the experience which will be gained from that working, whatever the results may prove to be.

But it is to the lower gates and to their machines that we desire more particularly to direct attention here. The lower gates are built of steel; the back or up-stream side of each leaf is curved, being in fact an arc of a circle which is concentric with the centre line of the leaf, passes through the centre of the bearings of the heel post and of the mitre post and was drawn to a radius of 66 feet 4¾ inches, while the down-stream side was made perfectly straight so as to form a chord of the arc; on plan, therefore, the gate is a segment of a circle and consequently has ample power of flotation. Each of the two gate machines by means of which the leaves of the lower gates are opened and closed is driven directly by a reversible pneumatic engine, an engine operated by compressed air, running at the rate of 370 r.p.m., and at that speed indicating 40 h.p. The engine speed is therefore lower than that of the motors in the Panama Canal electric machines, but still is considerable, and naturally has required the interposition of reduction gearing between the engine and the gate. This gearing has a ratio of 700 to 1, and its details are as follows: a pinion on the crank shaft of the pneumatic engine drives a spur wheel on an intermediate "jack" or first motion shaft; on the outer end of this shaft a bevel pinion is keyed which engages in a horizontal pinion and is keyed to a vertical shaft. The teeth of the horizontal pinion engage with the peripheral teeth of a horizontal wheel of which the centre or boss is formed of a steel casting from which the rolled joists, which form the arms of the wheel, radiate to the box which forms the base for the cast steel rim of the wheel. The rim base is built up of plates and angles and to it the toothed rim is secured. The bearing on which the horizontal wheel is supported consists of a stud which together with the wheel swings backwards and forwards, and which is borne by and supported in a footstep secured to the truncated cone of concrete which furnishes the foundation for the whole of the outer (and greater) part of the gate machine. The strut which forms the connection between the horizontal wheel and the gate is 28 feet 6 inches in length centre and centre, and is formed of two parallel steel joists laced together by means of flat bars. The end bearings of this strut consist of vertical studs, one of which is secured to the rim base of the wheel and the other is fixed on the curved centre line of the gate which has been previously referred to as having a radius of 66 feet $4\frac{3}{4}$ inches. A spring bearing is interposed between the outer end of the strut and the stud on the centre line of the gate on which the outer end works for the purpose of absorbing shock, and of thus avoiding injury to the gates or to the horizontal wheel in the event of sudden stoppage of the moving gate, or other untoward event taking place during the movement of the gate. The stud on the centre line of the gate is fixed at a point rather more than one-third of the distance between the bearing faces of the heel post and the mitre post in each leaf, and the curve which that stud describes as the gate travels out or home has a radius of 23 feet. One-half of one revolution of the horizontal wheel is sufficient to provide the stroke of the connecting rod which is required to provide the full travel of the gate in either direction.

The gate machines are more than ordinarily powerful for the positions which they occupy, as they were designed and constructed in such manner that they are capable of operating the gates at low water against a differential head of water of 15 inches. The machines and the engines which drive them are housed in sunken pits which were formed in the concrete work; the floors of the pits are 5 feet below the level of the surface of the coping of the lock; this level has an elevation of 530·00; while the h.w.l. of the Mississippi at Keokuk is said to be 525·00. The gate machines should therefore be free from danger of any injury from the inflow of the water from the river except at phenomenally high floods; while the complete manner in which they are housed has assured their being out of the way of the lock gatemen who handle the traffic which is passed through the lock.

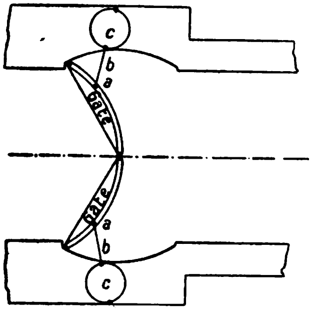

FIG. 29. GATE MACHINES AT LOCK IN KEOKUK DAM.

Diagram showing relative positions of machines and gates.

a Connection with gate.
b Connecting rod.
c Horizontal spur wheel.

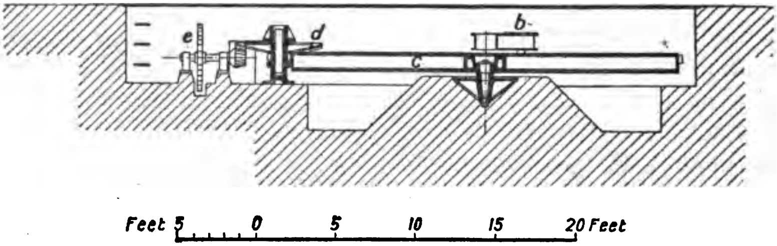

FIG. 31. GATE MACHINES AT LOCK IN KEOKUK DAM.

Section of pneumatic machine.

b Connecting rod.
c Horizontal spur wheel.
d Bevelled gearing.
e Spur gearing.

The principle which governed the design of the gate machines in the Mississippi lock at Keokuk, and generally the way in which the design was developed in detail, will be apprehended if examination be made of Figs. 29 to 32; while a comparison of these illustrations with Figs. 23 to 26, which relate to the gate machines on the Panama Canal, will be sufficient to show how strong the family likeness between the two designs is—not only in principle, but in the way in which the principle was worked out, especially if allowance be made for the difference in motive power. When these circumstances are taken in conjunction with the fact that whereas the Panama machines were constructed by and for the United States Government, the Keokuk machines were built under the auspices of and for the purpose

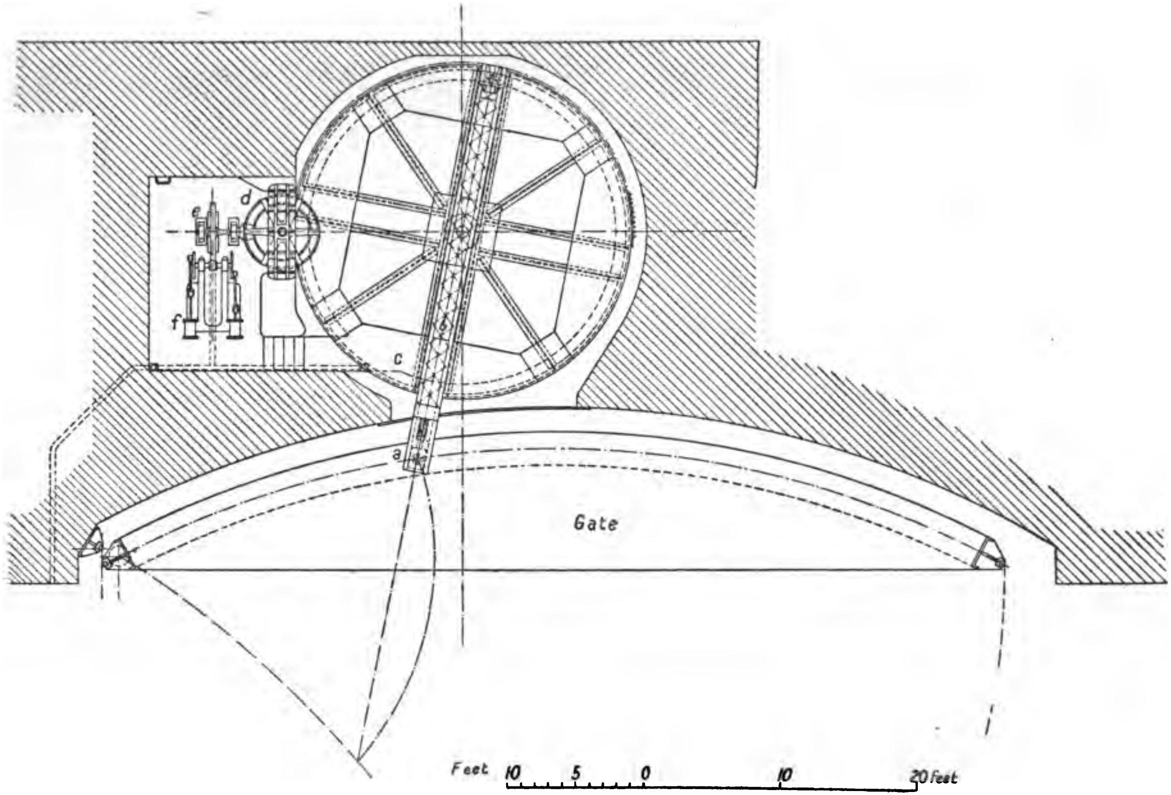

FIG. 30. GATE MACHINES AT LOCK IN KEOKUK DAM.

Sectional plan of pneumatic machine.

a Connection with gate.	*b* Connecting rod.	*c* Horizontal spur wheel.
d Bevelled gearing.	*e* Spur gearing.	*f* Pneumatic engine.

of being operated by the same Government, it will appear that the resemblance between the designs is due to identity of policy as well as of similarity of purpose.

In connection with the pneumatic motive power for the Keokuk machines, which although not unique (see p. 74) is unusual for the working of gate machinery, the observation may be added that the fact that compressed air was required at Keokuk for the purpose of raising the submersible gates at the upper end of the lock, and in the dry dock, was presumably the determining factor in the choice of pneumatic engines for the operation of the gear for opening and closing the lower gates of a lock which is situated in such proximity to the largest hydro-electric power plant in the world.

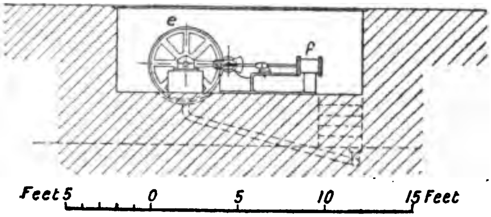

FIG. 32. GATE MACHINES AT LOCK IN KEOKUK DAM.

End elevation of pneumatic machine.

e Spur gearing. f Pneumatic engine.

Finally, so far as Keokuk Lock is concerned, the sluices by which the levels of the water in the lock are controlled are of the cylindrical valve type, which while again reminiscent of some parts of the sluice machinery in the locks on the Isthmian Canal to which reference will be made in the following chapters, may serve to indicate that a hitherto neglected type of lock sluice is at last coming into its own in the United States of America, an indication to which additional support will be given by other facts to which attention will also be directed.

CHAPTER VI

MACHINES FOR WORKING CAISSONS WHEN USED IN PLACE OF GATES

In the foregoing chapters attempt has been made to describe *inter alia* the evolution of the machines which are now employed for the operation of the gates by which in the majority of instances entrances to docks and basins, as well as locks, are controlled. But all dock entrances, and even all locks in which the levels are regulated mechanically, are not fitted with gates of the types which have been considered in the chapters referred to. In not a few cases both entrances and locks have been fitted with structures which are of varying forms, which are sometimes of quaint and curious design, and which have come to be known in engineering *parlance* as "caissons."

The word "caisson" was derived originally from the Latin, but was imported into English through the medium of the French language. The French word *caisson* meant in the first instance a chest or case, but in the course of time, came to have more than one technical significance. Even in Civil Engineering the word has various meanings, amongst these being that of a structure which is provided instead of gates in a lock or a dock entrance, and which serves for the maintenance of water in, or for the exclusion of the water from, a dock or basin, or a reach in a canal.

Caissons, like dock gates, have been evolved from very simple primeval forms, but have grown in dimensions and in complexity of design in the process of development. The history of the development is wrapt in some obscurity, is unimportant, and will not be pursued here. Sufficient to say that caissons were originally constructed of timber, that subsequently they were built of wrought iron, and that now under the stress of existing circumstances they are usually built of mild steel.

Modern caissons are, generally speaking, of three types, the first or primary type being that commonly known as that of the "ship" caisson, in which the structure is approximately of shipshape build, and is capable of being floated into and out of position whether in a dock entrance or elsewhere. The second type is rectangular and box-like in section, that is to say, that it has vertical sides which are connected together by transverse frames and plates which form (*a*) a floor for the caisson; (*b*) one or more intermediate decks; and (*c*) an upper deck upon which a roadway and frequently a railway are formed. This type of caisson slides into or out of a special recess or camber* constructed for its reception, on one side of the entrance which the caisson is intended to close.

The third or rolling type of caisson is from a structural standpoint generally similar to the second type; except that in it sliding friction is converted into rolling friction. The rolling type may be divided into three sub-types or patterns, namely:—

Pattern A, in which the body of the caisson is fitted with a series of wheels revolving on independent axles. These wheels travel over or along rails which are laid for them in the floor of the lock or entrance in which the caisson is to work.

Pattern B, in which this order is reversed, the underside of the caisson being fitted with sills or keelsons on which the structure is borne over a series of wheels which revolve on axles in boxes.

Pattern C, the use of which is limited to waterways where but a moderate amount of headway is required, and in which the wheels are fitted into frames which travel to and fro on rails carried on an overhead gantry supported by stanchions or brick pillars, and from which the caisson is slung by means of suspended bars.

Caissons have a general advantage over a single pair of gates as they are capable of sustaining a head of water in either direction, and can be constructed in such manner as to furnish a roadway across the lock or entrance capable of carrying wheeled vehicles of any weight, such as heavy locomotives or the motor lorries which are now finding an extended vogue in the conveyance of traffic to and from docks. The most suitable case for the use of a caisson is therefore that of an entrance in which differential head may be experienced in both directions from time to time, and in which a road and railway across the entrance will be required, as in such case the cost of the caisson will be less than that of a double pair of gates and of a swing or other opening bridge.

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* Chamber.

In considering the gear for the operation of the caissons, which is the subject of interest in this chapter, it should be observed first that there is one item in the machinery which is common to all types and patterns, namely an efficient pumping plant upon which the flotation (whether partial or complete) and therefore the mobility of every caisson depends. In the case of the ship caisson there are many instances in which no other item is required, as in such case the operations required for removal and replacement are carried on in the same way as those required for the removal of a barge from her moorings from one part of a quay to another. It follows that in the working of a ship caisson the first operation is to cause the caisson to float by pumping out the ballast water by which the caisson is weighted into place, thus lifting the structure out of the groove in the floor and sides of the entrance; after which the remaining machinery is represented by ordinary ropes and tackle, assisted it may be by hydraulic capstans and fairleads upon the quays of the entrance, or of the dock to which the entrance gives access; although in cases of specially large caissons for the closing of entrances of great width the caissons themselves are fitted with capstans which are fixed at each corner of the upper deck and which are at times of some assistance in the handling of the unwieldy craft.

Amongst the specially wide entrances referred to are the locks on the Panama Canal, in which, although lock gates are used for traffic purposes, ship caissons have been provided for the upper and the lower end of each lock in order to permit of the locks being pumped dry when cleansing, painting, and repairs of the subaqueous works therein are required. The caissons are of considerable dimensions; their net length is 112 feet 6 inches, their maximum beam 36 feet (moulded), and their depth 65 feet. The ordinary draught is 32 feet, but this can be increased to 61 feet when required. The pumping plant in these structures which has already been described as the primary item of machinery equipment for any caisson, is of exceptional power, four centrifugal pumps having been fitted into each vessel. The pumps are driven by electric motors, and three of the pumps have suctions of a diameter of 20 inches in each case, while the diameter of the fourth suction is 8 inches. This exceptional pumping power is due to the fact that the plant will be employed not only for discharging the water ballast from the caissons, but for pumping the water out of the locks where "unwatering" of any lock is required. Beyond these pumps the only machinery provided for the caissons consists of two hand capstans on the upper deck, which are intended to assist in such movements of the caissons as may become necessary.

With regard to the sliding type of caisson, three recent British examples are at hand. The first example is that furnished by the caissons with which the new entrance locks to H.M. Dockyard at Portsmouth were fitted, at the westerly or seaward ends of these locks. The locks are two in number and, in addition to the sliding caissons at their westerly ends, were furnished with ship caissons at the easterly or dock end of each lock.* The new Portsmouth locks are identical in design and dimensions, and the caissons at both ends were constructed so as to be interchangeable. An important feature in the design of the locks is that each lock can, when required, be used as a dry dock. For this reason, while the available width of the locks for locking purposes is 110 feet, the width between copings is 119 feet. The depth at the seaward ends of the locks is 33 feet at L.W.S.T., and is 46 feet 6 inches at H.W.S.T. The side chambers or recesses in which the sliding caissons are housed were formed on the northerly side of each lock, and the caissons were built so as to furnish a railway communication across the entrances as well as a roadway for vehicular traffic; and were also built to take pressure on both sides.

The machinery required for the operation of the sliding caissons is worked by means of compressed air, the working pressure throughout being 50 lb. per square inch. The pumping plant by which the ballast water is discharged from the caissons for the purpose of effecting mobility consists in each case of a Hayward-Tyler horizontal duplex power pump, capable of discharging 20,000 gallons per hour.

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* These important works were begun in 1907 when Sir Edward Raban, K.C.B., was Director of Works to the Admiralty, and were completed in 1913 under Mr. T. Sims, C.B., M.Inst.C.E.

The arrangement of the compressed air engine and gear by means of which each caisson is hauled into and out of its position in the lock, is shown in Figs. 33, 34, and 35,* which also show the manner in which the compressed air engine tilts the camber deck (by which each recess is covered) when it is required to house the caisson out of the way of the traffic. The camber decks were provided for the purpose of maintaining the continuity of the road and railway at times when the caissons are in position in the locks; but each camber deck is hinged at its landward end in such manner that it can be lifted from an intermediate point, and thus tilted at the outer or dock end to an extent sufficient to permit the caisson to be passed under the camber deck and into the recess when a vessel is to be berthed in the lock. (Figs. 36 to 42.)

Each caisson is hauled into or out of the recess in which it is accommodated by means of two steel pitch chains. These chains are led round two pairs of sprocket wheels, of which the wheels of one pair are secured to the driving shafts of the hauling machine, while the other pair work in bearings secured to the side walls of the recess. To allow for some lateral play in the hauling gear and thus to provide for a measure of flexibility during the movements of the caisson, a hauling beam is fitted to the chains and is attached to the caisson in such manner as to give the play required. It should be added that the operating gear for the movement of the caisson has been interlocked with that for the lifting of the camber deck in such manner that it is impossible that the movement of the caisson shall be commenced unless and until the tilting of the camber deck has been completely effected, or vice versa to begin to lower the camber deck until the caisson is fully housed in the recess.

Another example of a modern and important sliding caisson may be seen in the caisson with which the new dock at the north end of the Liverpool dock system is fitted. That dock was opened by H.M. King George V in 1913, and was by him named the "Gladstone Dock." The dock is not of great dimensions, but it has a special importance of its own as it forms at the present time the

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* These figures were derived from the working drawings which were prepared by Messrs. Swan, Hunter and Wigham Richardson, Ltd., of Wallsend-on-Tyne, who supplied the caissons and their machinery to the Admiralty, and whose kindness and that of the Director of Works has rendered the publication of the figures possible.

CAISSON HAULING GEAR AT PORTSMOUTH DOCKYARD.

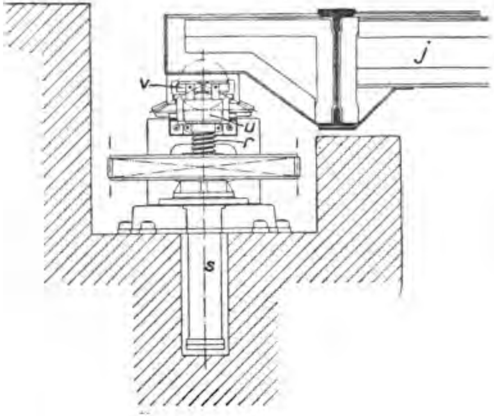


FIG. 36.

END ELEVATION OF LIFTING JACK FOR TILTING THE CAMBER DECK

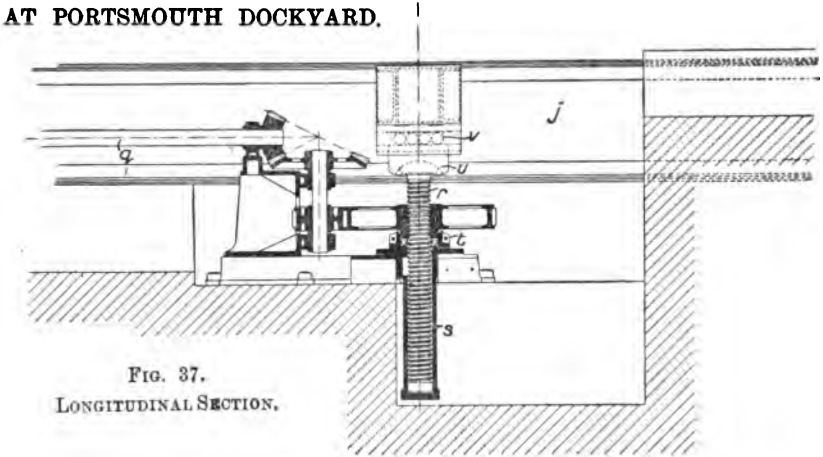
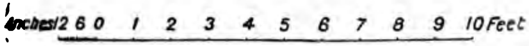


FIG. 37.

LONGITUDINAL SECTION.



j Camber deck.
q Driving shaft.
r Screw jack.
s Guide for screw.
t Ball thrust bearing.
u Rocker head.
v Roller bearing.

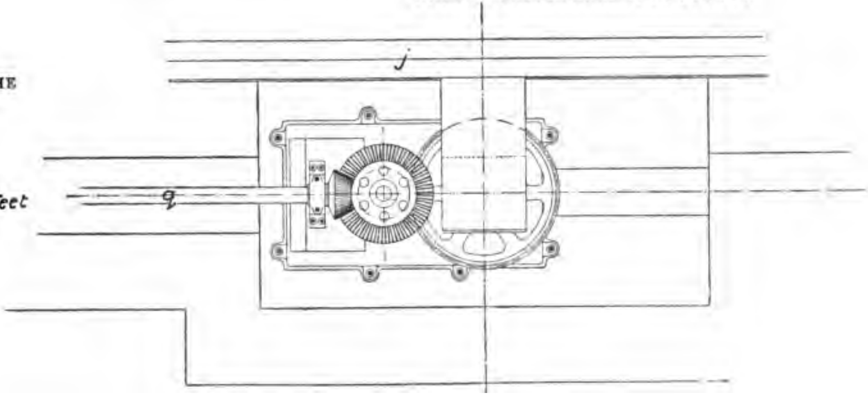


FIG. 38.—PLAN.

CAISSON HAULING GEAR AT PORTSMOUTH DOCKYARD.

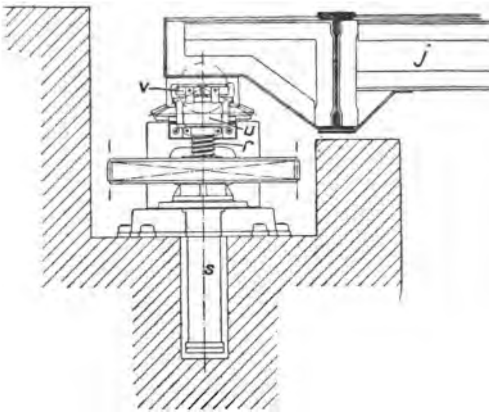
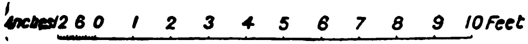


FIG. 36.

END ELEVATION OF LIFTING JACK FOR TILTING THE CAMBER DECK



j Camber deck.
q Driving shaft.
r Screw jack.
s Guide for screw.
t Ball thrust bearing.
u Rocker head.
v Roller bearing.

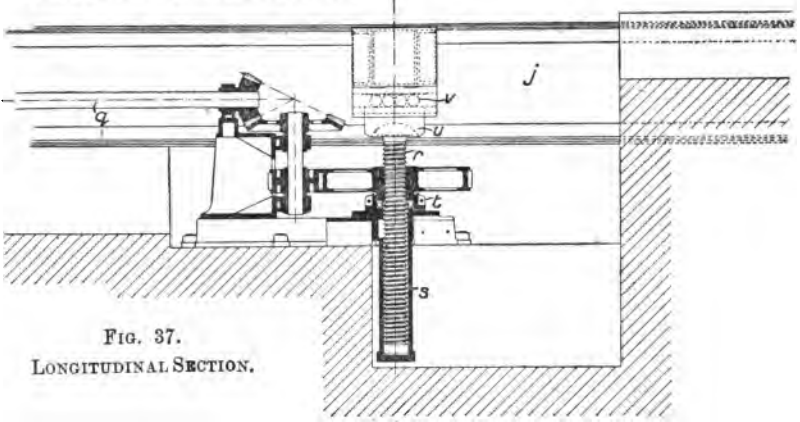


FIG. 37.

LONGITUDINAL SECTION.

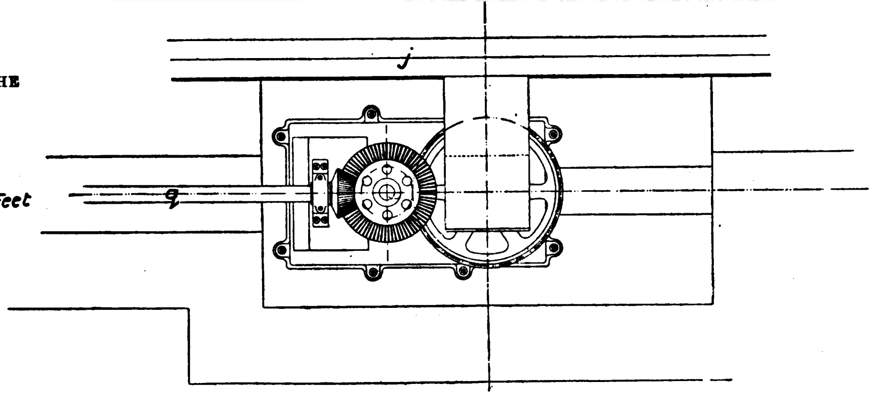
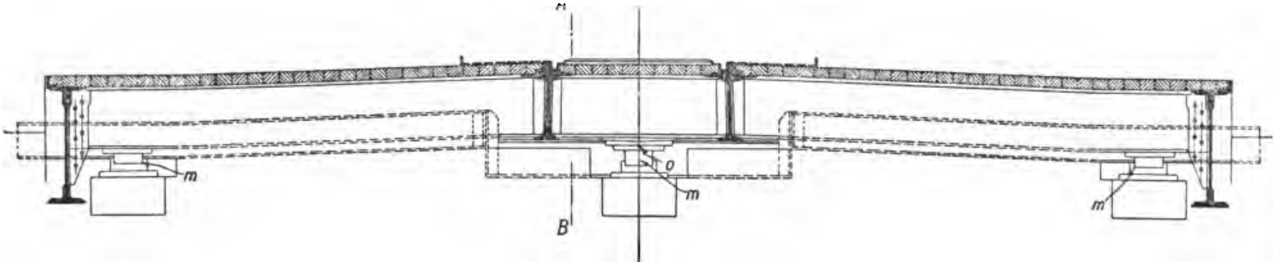


FIG. 38.—PLAN.

CAISSON HAULING GEAR AT PORTSMOUTH DOCKYARD.



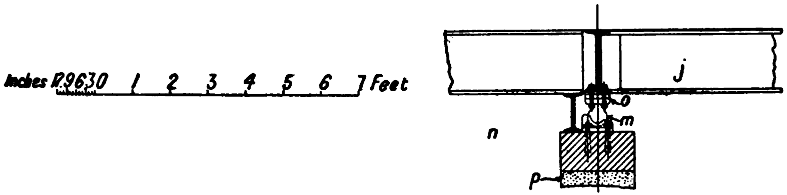


Fig. 39. Detail of Hinged End of the Camber Dock.   Fig. 40. Section on line *A B*, Fig. 39.

m Hinged joints.
j Camber deck.
o Folding wedges for adjustment of central hinge.
p Dam wall of machinery chamber.
n Chamber of machinery.

seaward boundary of the great line of docks on the Lancashire side of the Mersey. The caisson itself contains some original features which are beyond the scope of this chapter, and which were shown clearly in an illustrated description of the work which appeared in "Engineering" in October, 1913. The entrance to the Gladstone Dock is 120 feet in width, and the sill thereof is 25 feet below the level of the old dock sill, that is to say, it carries a depth of water at L.W.S.T. of 15 feet and at H.W.S.T. of 46 feet. The caisson itself has a length of 124 feet on the riverward face, and a length of 132 feet on the dockward side, a beam (moulded) of 25 feet, and a depth over all of 52 feet 6 inches. Like the new entrance locks at Portsmouth, the Gladstone Dock was "contrived a double debt to pay," i.e. to serve the purpose either of a wet dock or of a dry dock as may be required from time to time; for which reason the caisson was constructed in such manner as to be capable of standing pressure on both sides. The recess into which the caisson is drawn when a vessel is to be worked into or out of the dock, is on the southerly side of the entrance, and the machinery by which the caisson is handled into or out of the recess is shown in Figs. 43 and 44.* Neither road nor railway communication was required across the entrance to the dock, consequently the upper deck of the caisson carries a footway with a width of 6 feet only; and the operating machinery is used for no other purpose than that of hauling the caisson backwards and forwards. For the discharge of the water from the ballast tanks, the caisson is fitted with two 10-inch pumps of the centrifugal type and electrically driven; and during the period of movement the caisson slides on two greenheart fenders, one of which is fixed in the line of each side, and the glissade is effected on bearings formed of polished granite.

The machinery by which the caisson is operated consists of two hauling drums which are secured to one continuous shaft. The drums are of cast iron, are accurately grooved for the reception of wire ropes, and are driven by means of two independent electric motors which work through the duplicate reduction gearing which is interposed between each motor and the hauling drum. The motors are reversible, and are of such power that each motor is

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* The drawings from which these figures were prepared were lent through the kindness of Mr. T. M. Newell, M.Inst.C.E., Engineer-in-Chief to the Mersey Docks and Harbour Board. The contractors for the caissons and for the operating machinery were the Motherwell Bridge Company, Ltd.

CAISSON HAULING AT THE GLADSTONE DOCK, LIVERPOOL.

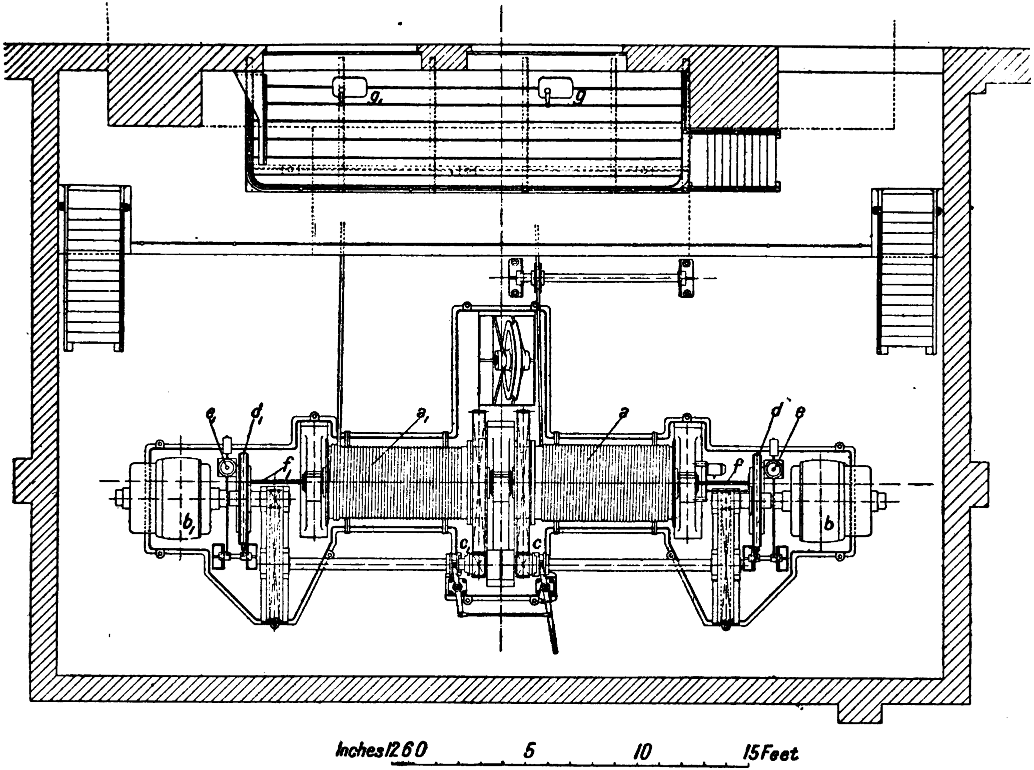

FIG. 43. PLAN OF HAULING MACHINERY.

$a\,a_1$ Hauling drums. $b\,b_1$ Electric motors. $c\,c_1$ Clutches. $d\,d_1$ Brake wheels.
$e\,e_1$ Solenoids for brakes. $f\,f_1$ Overwinding switch for brake solenoids. $g\,g_1$ Controllers.

capable of performing the whole of the work required for the movement of the caisson; the reduction gearing is therefore fitted with clutch connections so that one motor only can be in operation at the same time. The motors run at the rate of 350 r.p.m., and are of 150 b.h.p. each. The duplicate reduction gear consists in each case of a steel pinion on the motor shaft, which engages with a spur wheel keyed on to the outer end of a second motion shaft, to the inner end of which another pinion is keyed which drives one of two spur wheels which are secured to the continuous drum shaft, at points on that shaft near to the inner end of each drum. The teeth of the gear are all machine cut, while the spur wheel on the second motion shaft (which is driven from the motor shaft) works

CAISSON HAULING GEAR AT THE GLADSTONE DOCK, LIVERPOOL.

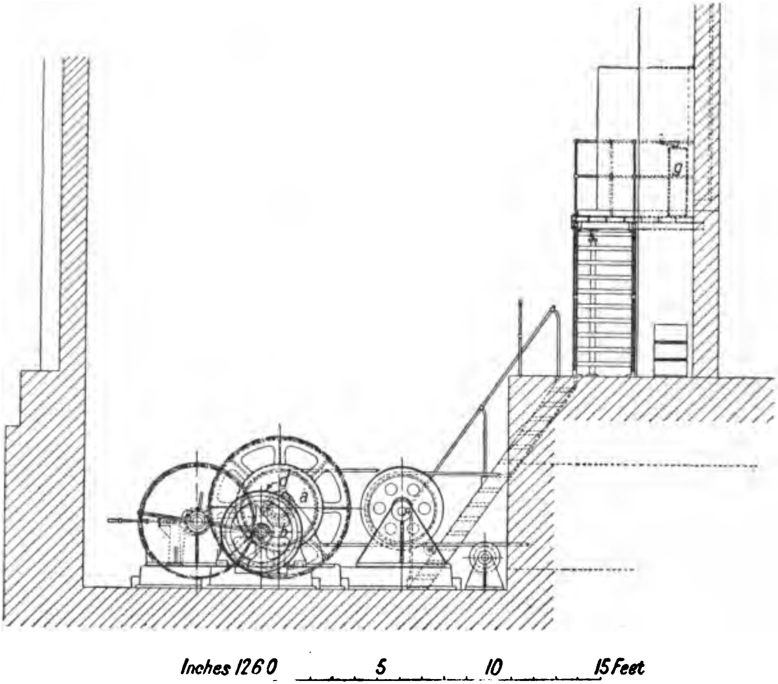

FIG. 44. END ELEVATION OF HAULING MACHINERY.

a Hauling drums. *b* Electric motors. *d* Brake wheels. *g* Controllers.

in a bath of oil. On the motor shaft a massive brake wheel is keyed between the motor and the pinion; this brake wheel is controlled by a solenoid and an overwinding switch arrangement which comes into action at any moment at which the caisson may pass beyond the limits of its required travel, at which moment the solenoid is released and the movement of the motor is arrested by the brake. The hauling gear is operated by a man who works the machinery by means of two controllers of the tramway type, and who from a raised platform on which these controllers are fixed, is able to view the movements of the caisson throughout its whole stroke. The connection between the drums and the caisson is effected by steel wire ropes which are arranged in such manner that when the caisson is being drawn across the dock one rope is hauling and the other is paying out, the action being reversed when the caisson is being drawn into its recess.

A period of about ten minutes is required to complete the traverse of the caisson in either direction, but this period, although four or five times as long as would be required for the operation of gates of similar size, is not of any particular importance in the tidal conditions which obtain in the narrows of the Mersey, and under which so brief a period is available at and near high water for the docking or undocking of large steamers, that it can never become necessary to open and to close the entrance to the Gladstone Dock more than once in the course of twelve hours.

A third example of the sliding type of caisson, and one on a great scale, has been furnished in the works which are now in course of construction at Rosyth, which is situated on the northerly side of the Firth of Forth, where Mr. T. Sims, C.B., is carrying out for the Admiralty a magnificent system of wet and dry docks for the accommodation of vessels of H.M. Navy. Eight caissons in all are being built at Rosyth, but of these two are of the floating type and are briefly described at page 95.

The six sliding caissons are referred to as *A*, *B*, *C*, *D*, *F*, and *G* respectively. Caisson *A* will control the emergency entrance to the docks which has a net width of 125 feet, and has a weight of 1030 tons. Caisson *B* is for the outer end of the entrance lock (which has an effective width of 110 feet) and has a weight of 1205 tons. Caisson *G* at the inner end of that entrance lock has a weight of 905 tons. Caissons *C*, *D*, and *F* are for Rosyth dry docks, and in each case have also a weight of 905 tons. At high water of high tides the pressure on the sliding ways of these caissons are as follows: On *A*, *C*, *D*, *F*, and *G*, 10 tons; on *B*, 25 tons, which is at low water of spring tides increased to 101 tons.

The general type of gear by which the sliding caissons at Rosyth are operated is shown in Figs. 45, 46, 47, and 48.* In every case the gear is operated by means of electric motors, hand gear being provided for use in the event of a contingency arising which might render the electric motors temporarily unavailable. Each set of hauling gear is fitted with two motors which drive through two separate trains of reduction gear on to two chain sprocket wheels. The caisson is in each case connected with the gear, and is operated by means of two haulage chains which are attached to the ends of a special hauling beam by means of special links in the chains which are provided for the connection.

In order to make the gear interchangeable and in this way to reduce the number of the spare parts of the gear which are required, each installation of hauling gear was designed and fitted with a sufficient margin of strength to render it capable of taking a pull of 70 tons on the pair of chains, each chain being designed to take a pull of 40 tons. For the same purpose all the motors are capable of developing 100 b.h.p. with 500 r.p.m., and a direct current supply of 440 volts. Two motors are fitted to each installation and will be used in ordinary working, but as a matter of fact one motor when running alone is capable of operating any of the caissons. The electric controllers are of the drum type, one controller being fitted for each motor, both controllers being mechanically connected and being operated by a spindle which connects through the roof of the machinery chamber. Safety gear to prevent over haulage is fitted in each case, while the rate of haulage throughout is 25 feet per minute, and the stroke or range of travel varies from 132 feet to 118 feet.

Passing on now to examples of the rolling type of caisson, it should be observed that the difference between this type and the sliding type consists generally in the fact that instead of being

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* The figures were prepared from working drawings kindly supplied (with the permission of the Director of Works) by Sir W. Arrol and Company, Ltd., of Glasgow, who were the contractors of the Rosyth caissons and machinery.

CAISSON HAULING GEAR AT ROSYTH DOCKYARD.

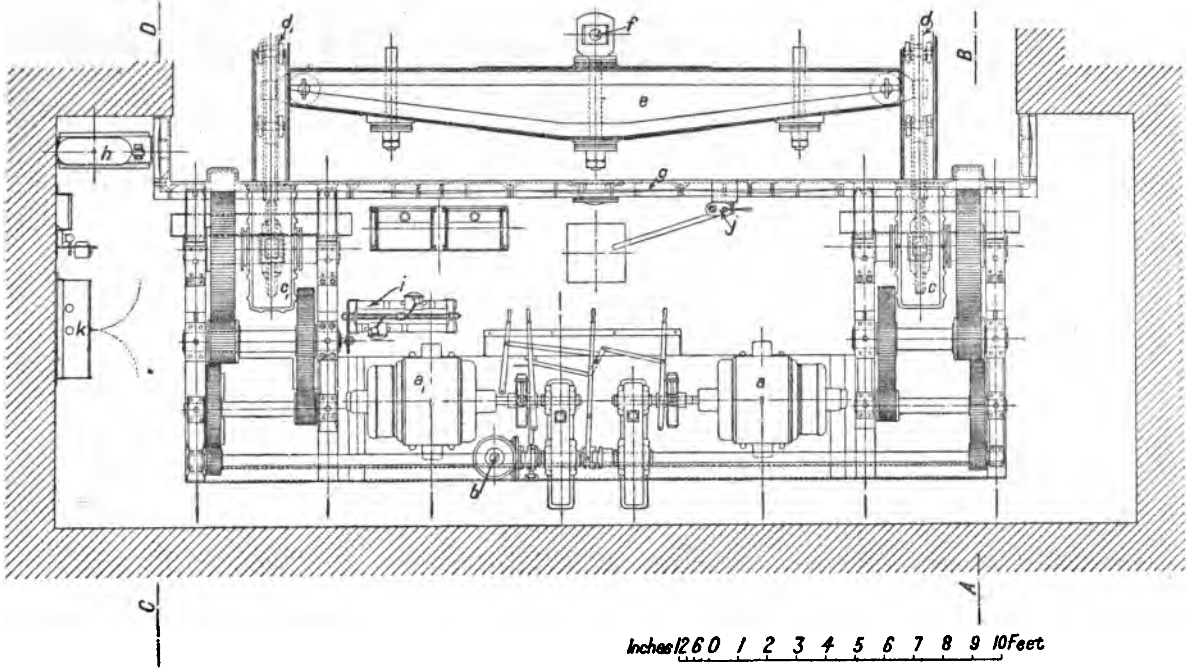


FIG. 45. PLAN OF HAULING MACHINERY.

$a\,a_1$ Electric motors.
e Hauling beam.
i Overwinding switch.
b Hand capstan.
Connection with caisson.
j Hand pump.
$c\,c_1$ Sprocket wheels for haulage chain.
g Dam wall of machinery chamber.
k Main switchboard.
$d\,d_1$ Haulage chains.
h Controllers.

CAISSON HAULING GEAR AT ROSYTH DOCKYARD.

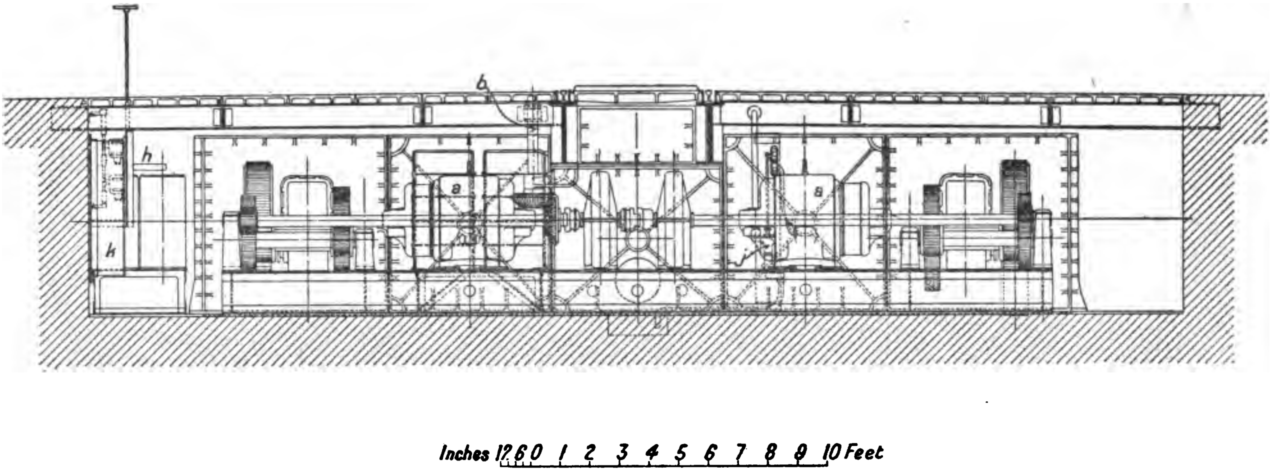


Fig. 46. Elevation of Hauling Machinery.

a Electric motor. *b* Hand capstan. *k* Main switchboard. *j* Hand pump. *h* Controllers.

fitted with slides on the feet of the structure the rolling caisson has an equipment of supporting wheels and axles through which frictional retardation is reduced, and the danger of seizing is almost eliminated; besides which the extent of the pumping required to effect mobility is diminished and saving in the power of the hauling machinery rendered possible.

One of the first of the rolling caissons of which record remains was built according to the patented design of the late Mr. W. R. Kinipple, at the Garvel Graving Dock, in the Port of Greenock, and on the southerly side of the Clyde. This caisson was completed in 1874 and is still in use. It was followed by a rolling caisson which was fitted in 1878 to a lock in a Dutch canal known as the Kampen Canal, Kampen being a town in Holland, which is situated on the easterly side of the Zuider Zee.

CAISSON HAULING GEAR AT ROSYTH DOCKYARD.

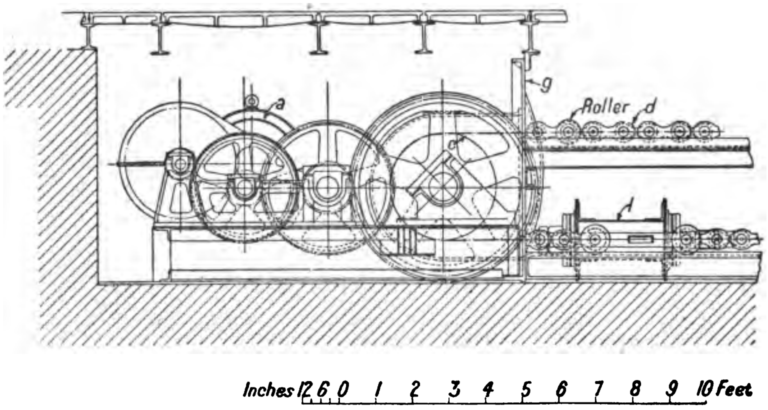


FIG. 47. SECTION ON LINE *A B*, FIG. 45.

a Electric motor.
c Sprocket wheel for haulage chain.
d Haulage chain.
e Hauling beam.
g Dam wall of machinery chamber.

At a somewhat later date, 1885, two caissons of the Kinipple pattern were constructed for the James Watt Dock in Greenock, one at the western entrance through which that dock is entered from a tidal harbour which forms the approach to the dock from the Clyde, and the other at the eastern entrance through which the dock is reached from the "Great Harbour," which is an enclosed area on the southern foreshore of the Clyde. The caissons, like that of the Garvel Graving Dock, were constructed of wrought iron and have done good service, as is evidenced by the fact that they both remained in place until 1913 when the eastern caisson in the James Watt Dock was removed, was dry docked for cleaning, painting, and repairs, and was then replaced in position. The entrances to the James Watt Dock, for which the caissons were constructed, have an average width of 75 feet, that is to say, the width at sill level is 70 feet, and that at coping level 80 feet. The depth of water on the sills is 32 feet at H.W.S.T., and 22 feet at L.W.S.T., the height of the coping level above that of the sill being 40 feet.

CAISSON HAULING GEAR AT ROSYTH DOCKYARD.

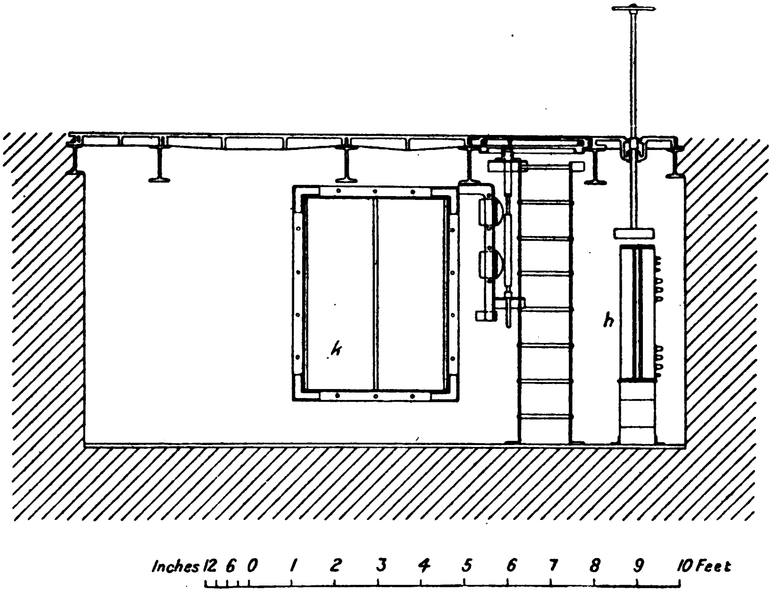


FIG. 48. SECTION ON LINE *C D*, FIG. 45.

h Controllers. *k* Main switchboard.

In rolling caissons as usually constructed the rollers (which are really wheels and axles and not rollers) are attached to the structure of the caisson itself, and the rails on which the wheels run are secured to the masonry of the groove in the sill of the lock or entrance in which the caisson moves. In the caissons for the James Watt Dock this order was reversed. The wheels and axles, of which there are sixteen under each caisson, were fixed in the groove, while the rails (which bore on the peripheral faces of the wheels) were secured to the feet of the caisson. The wheels are formed of cast iron and are flanged, are 18 inches in diameter, and are spaced about 9 feet apart. The rails which form the keels of the caisson are of solid steel, 8 inches wide by 4 inches thick, and are secured to the angles at the feet of the caisson by means of countersunk rivets. Apart from this, the principal feature in these caissons is the manner in which the road and railway, both of which were required at each entrance, were carried on each caisson. The platform for the road and railway is supported on counterbalanced levers which are again supported by and which swing on pin bearings fixed on each side of the caisson. This device makes it possible to lower the platform until the supporting levers, the stanchions of the handrailings, etc., are brought to a horizontal position, in which position the platform, levers, and handrailings can be housed beneath the fixed decking which was built over the recess for the caisson. This decking is formed of rolled iron joists with jack arches between, and is competent to carry the heaviest loads which are required to pass over the quays and entrances of the dock. The platforms are lowered and raised automatically by means of what are styled "nosing rollers," which are attached to one end of the longitudinal girders of the platform, and by shoes which are fixed at the other end of the same girders. These attachments have a further advantage in that they hold the platforms firmly when in working position and stop vibration under heavy traffic.

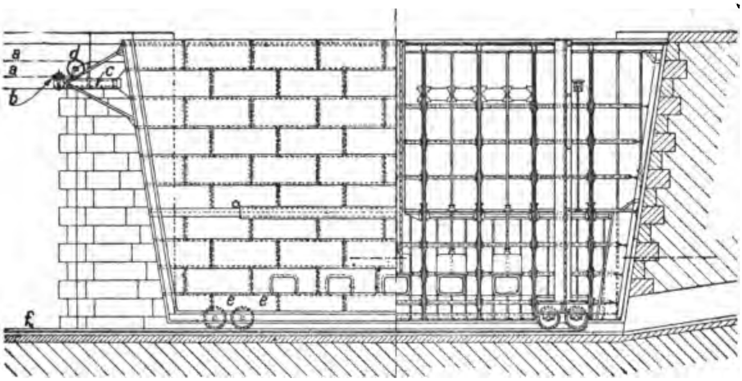
The caissons in the James Watt Dock are required to take pressure on both sides, for while the level of the water in the dock is usually above that in the estuary, the reverse condition sometimes obtains, the level without the dock being higher than that within.

The Greenock caissons are operated by means of hydraulic hauling machines. Each machine is driven by means of a three-cylinder reciprocating engine which actuates the gearing, by means of which gearing three speeds, quick, intermediate, and slow, are provided. It was considered that under normal conditions the weight to be moved on the rollers under each caisson would not be more than 40 tons, but in order to provide for the movement of the caisson if the watertight compartment should be filled with water (when the dead weight would be about 700 tons) the hydraulic engines were made of sufficient power to haul loads of 75 tons, and were fitted with the three speeds to which reference has already been made. The hydraulic pressure by which the engines worked is 750 lb. per square inch. Each caisson is hauled into and out of the recess provided therefor in four minutes, by means of two endless 1½-inch pitch chains which are attached to a yoke at the end of the caisson, and which pass round pitch wheels on a driving shaft at the inner end of the recess and round return wheels at the outer end.

A more modern example of the rolling type of caisson, and which was used in substitution for gates in a lock forming the sea entrance to a ship canal, has a pathetic interest at the time of writing (when the Continent of Europe is convulsed by the fierce war which is being waged between the great Powers) as the works in question were first seized by an enemy power and used for offensive purposes against the people by whom they were built, and against the allies of those people, and were then wrecked (because of that use) by those allies.

The works will doubtless be recognized; they are those which form the sea terminal of the Bruges Canal which was completed in 1905, and which was constructed for the purpose of restoring the connection between the ancient city of Bruges and the sea, and of thus reviving the commercial prosperity which the city enjoyed in mediæval times. As a part of the works a new harbour was constructed on the Belgian coast and was designated Zeebrugge (*Anglicè*, Bruges-by-the-Sea), at which place the coast line is pierced by a sea entrance which terminates in a lock, which provides access to the Bruges Canal. This lock, which lies approximately north and south, is fitted at each end with a caisson of the rolling type, and with recesses in the westerly wall into which the caissons can be drawn. The width of the lock at the entrance is 65 feet 8 inches, and as uniformity of level of the water is required in the canal, that level will, owing to tidal oscillations, be at times below sea-level and at times above it. For this reason the caissons had to withstand pressure on both sides. Both road and railway accommodation were also required across the lock, but no attempt was made to employ either or both of the caissons for these purposes, two special independent swing bridges being constructed across the locks, one for the road and the other for the railway. The sides of the caissons are vertical and parallel, while their ends are battered. The caisson dimensions are as follows: length 68

ROLLING CAISSONS AT ZEEBRUGGE.



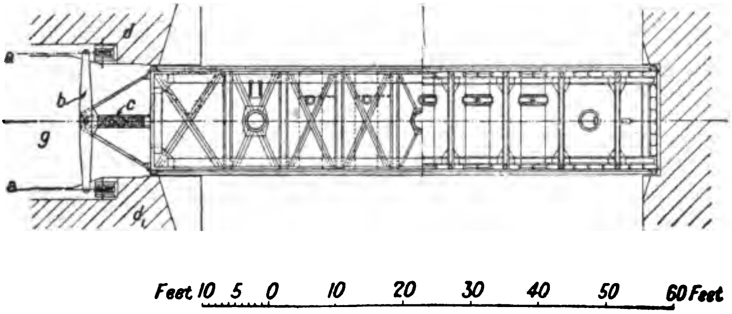


FIG. 49. ELEVATION OF CAISSON. FIG. 50. PLAN OF CAISSON.

a a Endless hauling chains.
b Hauling beam.
c Draw beam or horn.
d d Return pulleys.
f Roller paths.
g Recess for caisson.
e e Rollers.

feet at bottom and 80 feet 4 inches at top, beam 14 feet 9 inches, and height over all 41 feet 8 inches. The feet of each caisson are fitted with two pairs of wheels keyed to continuous axles at each end, making eight wheels for a caisson. These wheels travel on rails which are laid in the groove provided for the caisson in the bottom of the lock and in the continuation of that groove in the caisson recess. The wheels are 3 feet 3¾ inches in diameter. The caissons are hauled into and out of their recesses by means of electric winches which are fixed at the westerly or inshore ends of the recess. The reversible motor which operates each winch has a capacity of 20 kw. with a pressure of 440 volts, and in each case the power is conveyed from the winch to the caisson by means of two parallel endless chains which are carried round two sets of pulleys. The driving pulleys are keyed to the main shafts of the electric winch referred to, while the outward pulleys are secured to the recesses formed in the masonry at each end of the inward end of each caisson chamber. The arrangement by means of which the chains are connected with the caisson is shown in Figs. 49 and 50. It will be seen from the figures that a draw beam or horn projects from the upper part of the inner end of the caisson. The horn is stayed on both sides and in both directions to the end of the caisson to which it is attached, and that the outer end of the horn is fitted with a central pin through which a balancing beam for the adjustment of the load on the two chains is attached to the projecting horn, the hauling chains being connected with each end of the hauling beam. The caissons are opened and closed in three minutes, and up to the time when the canal was used as a base for German submarines, and when disaster fell upon it in the shape of shells from the great guns of the British warships, the caissons worked without difficulty and practically without hitch.

A further and recent example of a rolling caisson is furnished by the caisson at the No. 3 Graving Dock which was built at Govan (on the southerly side of the Clyde) by the Clyde Navigation Trustees.* That caisson is 87 feet 4 inches in length, 14 feet 4 inches in beam, and 36 feet in depth, measured to the top of the folding bridge which, when the caisson is in position, forms a connection between the two sides of the dock entrance, and in design resembles the rolling caissons at the James Watt Dock at Greenock (already described in these pages) in that the Govan caisson is fitted on the underside with two wrought iron keelsons which are each 8 inches wide by 4 inches thick, which bear upon and roll over cast iron brass bushed wheels which have a diameter of 18 inches, revolve on axles fixed in boxes laid in the floor of the caisson berth, and of which ten were provided on each side or twenty wheels in all.

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* The particulars of this caisson and the drawings from which the figures which illustrate the machinery therefore were prepared, were kindly supplied for the purpose of this work by Mr. W. M. Alston, M.Inst.C.E., the Chief Engineer to the Clyde Navigation Trust, while the description of the machinery is by Mr. G. H. Baxter, M.Inst.M.E., the Mechanical Engineer to the Trust.

The machinery by which the caisson is operated is driven by a direct acting reversible hydraulic engine, for which a pressure of 600 lb. per square inch is available in the mains. The engine has four gunmetal rams with a diameter of 5 inches and a stroke of 12 inches which work through two cranks on a crank shaft, which is geared up to the main shaft. The main shaft is extended laterally into and across the caisson chamber, two pitch chain pulleys being keyed on to the extension of the shaft. In line with these pulleys are two respectively corresponding pulleys which revolve in angle frames which are bolted to the masonry at each side of the inner end of the caisson chamber. The pulleys at each side of the chamber are connected together by means of two chains, into which the respective ends of a yoke is inserted and attached by shackles and pins to the chains in such manner that an endless system consisting of chains and yoke was formed. Each of the chains is fitted with a stretching screw to take up the slack, and the yoke is formed of steel channels plated at top and bottom, each plate being bossed at each end to receive the pin connections for the chains, and being further thickened at the centre where the plates were bored out to receive a swivel bolt which is 5 inches in diameter and is attached to the hauling bracket at the end of the caisson.

The travel of the caisson is about 98½ feet, and the gearing through which the hydraulic engine is connected with the main shaft, already referred to, has two speeds, a quick motion by which the travel over this distance is effected in five minutes, and a slow motion by which the same travel is accomplished in ten minutes.

The crank shaft of the engine runs at 55 r.p.m., and for the quick speed a spur wheel on the crank shaft, which has 58 teeth, gears into a corresponding wheel on the second motion shaft which has 60 teeth. On this second motion shaft is also keyed a pinion with 16 teeth, gearing into a spur wheel of 66 teeth which is secured to the third motion shaft; this shaft has another pinion of 16 teeth again gearing into a spur wheel with 60 teeth which is keyed to the fourth or main shaft, the extension of which carries the two pitch wheels for the chains already described. The slower speed is brought into action by throwing out of gear the wheel of 58 teeth and putting into gear a wheel at the other end of the crank shaft which has 39 teeth and which engages with a corresponding wheel of 79 teeth on the second motion shaft.

The machinery is provided with a hand movement which is operated through a capstan head fixed on a vertical shaft and driving through bevelled gearing the second motion shaft already described. It is also fitted with an automatic arrangement by which the valve which controls the hydraulic supply can be shut automatically when the caisson has travelled to the end of the chamber by means of a screw fixed to the main shaft and which works a wyper shaft. It has hitherto not been found necessary to bring this automatic arrangement into practical use.

Figs. 51 and 52 show the general arrangement of the machinery thus described in elevation and in plan, and also show a part of the endless system of parallel chains and of the yoke, by means of which the chains are connected with each other and with the caisson.

Another case in which a peculiar type of rolling caisson was employed in substitution for lock gates is that of the O-Becse lock of the Canal François in Hungary. The works of which that lock formed part were inaugurated in 1895, and therefore in order of time preceded those of the Bruges Canal. The Canal François is a member of a system of Hungarian Canals, through which the Rivers Danube and Tisza (a tributary of the Danube) are connected by means of a junction with the Danube near the town of Bexdan (which is about 29 miles above the point at which the River Drave flows into the Danube), while the junction with the Tisza is effected on the right bank of that stream and near the small town called

O-Becse. At that point caissons or "rolling gates" were installed in the lock which was constructed for the regulation of the levels of the water in the Canal François and in the River Tisza. Ordinarily the canal level is higher than that of the river, but as the river is subject to heavy floods, it rises under flood conditions to a height greater than can be safely permitted in the canal. The lock is, therefore, of a composite character, that is to say, it has three steps or levels, two of which are controlled by the rolling gates, and one (nearest the Tisza) which has ordinary gates and a pointing sill and which is thrown out of use at flood times. The rolling caissons were, therefore, like others which have been the subject of consideration in this chapter, constructed in such manner as to be capable of taking pressure on both sides, and do not of themselves differ in material point from the general run of structures of their class. Consequently the only features of interest in the O-Becse caissons are those connected with the arrangement by which the rolling gates are traversed in and out of their recesses. The width of the O-Becse lock is 52 feet 6 inches, the length of the caisson, the ends of which are vertical, is 55 feet 8 inches, while the beam (moulded) is 5 feet 5 inches, and the height 30 feet 1 inch. One of the rolling gates with the accessories thereof is shown in Figs. 53 and 54. It will be seen that the gate is suspended from a travelling frame or carriage which runs on four axles and four pairs of solid wheels. The wheels have central flanges on their tyres, and are supported in each case on twin rails which are again carried on the upper flanges of a horizontal girder which forms a constituent part of an overhead gantry, and which is supported by three sets of bracketed stanchions. The flood level in the Tisza is 261 feet 4 inches, the level in the lock at the gantry is 243 feet 1 inch. The head room at the gantry for the passage of vessels is, therefore, limited, and is reduced to 16 feet at times of high flood. For the connection between the caisson and the overhead carriage an elongated saddle of lattice work was constructed on the upper deck of the caisson, the lines of the vertical members being coincident with those of the verticals in the framing of the caisson. A footway is carried through the saddle which gives access to the cabin, from which the rolling gate is operated. The saddle and the gate on which it was built are connected with the travelling carriage by means of eight pairs of suspension straps formed of flat steel

ROLLING CAISSONS AT THE O-BECSE. LOCK

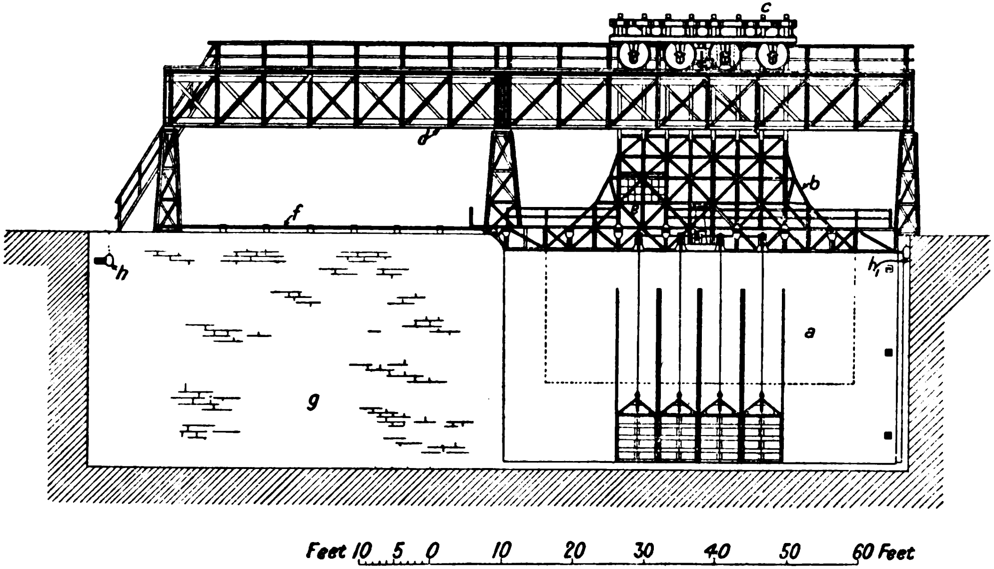

FIG. 53. ELEVATION OF THE CAISSON.

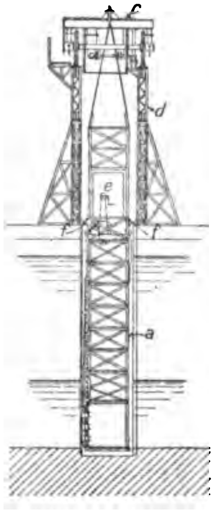

FIG. 54. SECTION OF THE CAISSON.

a Caisson.
e Operator's cabin.
b Suspension saddle.
f Guide rails.
c Travelling frame.
g Caisson recess.
d Gantry for travelling frame.
h Buffer blocks.

bars. The caisson is steadied in its movements to and fro by means of small side rollers which are attached to the upper strakes of the caissons and which bear against rails fixed to each side of the recess.

In the larger of the two caissons four hand pumps are fixed and are used for the discharge of the ballast water from the tanks. The power required for hauling the caissons into and out of their recesses is provided by means of electrical energy which is generated by the utilization of the differential head of water at the lock, water being diverted from the canal at a point above the lock and conveyed through an underground conduit to a turbine which was erected in a house at the lower end of the lock. The diverted water is finally discharged into the River Tisza at a point below the lock and out of the way of the traffic therein. The turbine drives a generator through which, under ordinary conditions, an ample supply of current is provided for all purposes, the differential head under these conditions being about 23 feet. A reversible motor is fixed on the travelling carriage in each caisson, by means of which the caisson is driven in one direction or another through a system of reduction gearing of the usual type.

The time required for the complete opening or closing of a caisson by the electric machinery is three minutes. Hand gear has been provided also for the operation of the caissons at flood times when the effective head of water at the lock is destroyed by the rise of the level of the water in the Tisza. The movement of the caissons is not frequently required at these times, but when movement has to be undertaken by means of the hand gear, twelve minutes are consumed in effecting the travel of a caisson, whether the movement be into the recess or across the lock.

As already mentioned, two of the Rosyth caissons are of the floating type, and their movement from one point to another is controlled by capstans, fairleads, and other means, as described in Chapter XIII. But the vertical movement is entirely hydraulic, is actuated by the manipulation of an ingenious arrangement of tanks, and although the system cannot strictly be classed under the term "machinery," still it presents some interesting features well worthy of notice.

The diagram (Fig. 54A) shows in skeleton form a sketch of the plan elevation and cross-section of one of these caissons. It will be observed that there are four decks, three of which, *A*, *C*, and *D*, are formed of solid plating throughout, and *B*, which is latticed and placed at such a level that when the caisson is resting on the sill, this deck will not be below the level of the highest recorded tide. Resting directly on deck *B* is the top water tank, placed near the centre of the caisson; it is divided into two longitudinal compartments by a baffle plate diaphragm. Decks *C* and *D* form respectively the top and bottom of the air chamber, and immediately below *D* is the ballast chamber, both of which extend from end to end of the caisson.

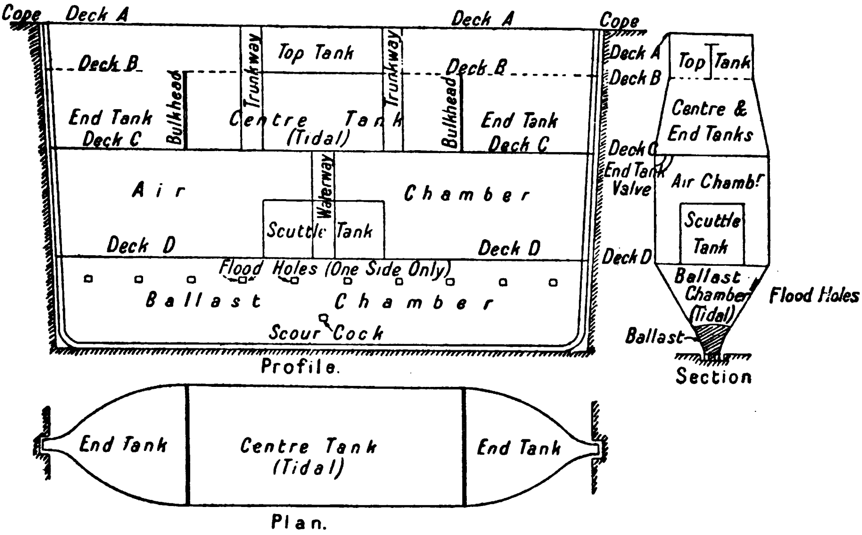

FIG. 54A.

Two transverse bulkheads are placed between decks *B* and *C*, dividing this space into two equal sized end tanks, and a centre tank equal in volume to the two end tanks together. Either in or below the air chamber what is termed a "scuttle" tank is formed, equal in capacity to the top tank. It will also be noted that openings or flood holes are made through the skin plating of the ballast chamber, but only on one side of it. Valves are fitted in the bottom of the end tanks, and these are connected to the outside water by pipes passing through the skin of the air chamber, but on the opposite side of the caisson to that in which the flood openings are made. In addition hatches and trunk ways are formed for access to the air and ballast chambers, also waterways where required, and these are indicated on the diagram.

The operation of either lowering the caisson into position across an entrance or of raising it is a very simple one. By way of illustration it will be assumed that the caisson is to be used to close the entrance of a graving dock which is to be afterwards pumped out.

It is assumed that the caisson is afloat with not more than the specified amount of freeboard, deck *C* being a few inches above water level, and with no water in the top tank, and that the centre and end tanks are also empty. The caisson must, of course, be stable in this condition by virtue of the ballast placed in the lower chamber above the keel.

Before being towed into position across the entrance the caisson is first partially sunk. This is done by shutting the end tank valves (if open) and filling the top tank from land mains or otherwise ; the caisson will then gradually submerge until the additional load is neutralized by the buoyancy of the end tanks. Deck *C* will now be submerged and the water in centre tank will be at same level as outside, since this tank is connected by the vertical waterway to the ballast chamber, as shown on the diagram, and the water is free to enter the ballast chamber from the outside through the flood holes.

By virtue of this partial submersion the caisson is more stable, and is now manœuvred into position across the entrance with the flood holes towards the graving dock. The valves of the end tanks are then slowly opened and the caisson sinks, finally bearing on the sill. While sinking it can be kept level by opening or closing one or the other of the end tank valves as required, and these valves can be left open. The top tank is now full and the tide simply rises and falls in the centre and end tanks.

The dock is now pumped out, and as the water level falls the centre tank gradually empties into the dock through the waterway and flood holes until finally the ballast chamber is full to flood-hole level, the top tank is full and end tanks are tidal. The dock is now empty, and the caisson is designed to be stable in this condition, and has in addition the friction of the meeting faces to overcome before it can lift.

To raise and remove the caisson, the dock is filled by means of the sluices in the side walls until the water is level outside and in ; then the top tank is emptied, and the caisson gradually rises, the centre and end tanks emptying at the same time. The caisson can then be floated away and the entrance cleared.

In any case where water from an outside source is not available to fill the top tank when the caisson is afloat, the scuttle tank, which is equal in volume to the top tank, is used instead. The end tank valves are first closed and the scuttle tank valve opened ; the caisson slowly submerges until it is brought up by the buoyancy of the end tanks. The sinking is completed as before by opening the end tank valves and the scuttle tank can then at leisure be pumped into the top tank while the dock is being emptied.

To repair the end chambers, the caisson is placed in position with the end chamber valves towards the dock, and is then sunk, as already described, by filling the top tank and opening the end tank valves. The dock is then pumped out, the end tanks discharging into dock as the water level is lowered. The top tank and ballast chamber are now full, the centre chamber tidal, and the end tanks empty. The size of the top tank is computed so that the caisson has no tendency to lift under these conditions, and there is in addition the friction of the meeting faces as a factor of safety.

To repair the ballast chamber the caisson is turned so that the flood holes face the dock and it is then lowered on to the sill, as already described. A very high tide is selected and the end tank valves closed at the highest level ; the dock is then pumped out and the ballast chamber is emptied through the scour cock placed low down on flood hole side. The water in the top tank and in the end tanks should be sufficient to counteract the buoyancy, while the friction provides additional safety.

The safety of all the operations depends on the dimensions of the top tank being of such a size that the weight of the contained water exceeds the buoyancy of the caisson under any of the working conditions, by a sufficiently large margin for safety, generally about 5 tons ; this together with the friction should suffice to prevent lifting.*

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* As an additional precaution to prevent lifting in the event of leakage of the tanks, an arrangement for holding down the caisson when resting on the sill is provided at each end.

One great advantage of this type of caisson is that little pumping is required, more especially if the top tank can be filled from an ordinary gravitation water supply.

Floating caissons are especially useful, by reason of their mobility; for emergency working and in the event of accident to the ordinary gates or sliding caissons the floaters can be used instead, being placed in position across the entrance in special stops or recesses purposely made to fit them in the side walls and outer apron.

CHAPTER VII

SHUTTLES, PADDLES, SLUICES, AND OTHER APPLIANCES FOR THE REGULATION OF WATER LEVELS

ONE of the striking advantages which are possessed by a gateway in a maritime depôt or highway, whether the gateway be in the form of an entrance to a tidal basin or to a dock or of that of a lock in a canal or a canalized river, lies in the fact that the surface level of the water at the gateway is mobile and can be regulated, i.e. either raised or lowered, and that under the influence of gravity alone. For the purposes of the regulation which is required, two levels are necessary and must be maintained, an upper level and a lower; these levels, moreover, must be connected either by openings in the gates or by conduits, however formed, through which water can flow from the one level to the other; and the conduits must be fitted with sluices or valves or other means by which the flow through them may be controlled. The gates, and the machines for their operation which have formed the subject of preceding chapters, are in themselves the means by which the differential levels are maintained in maritime depôts and highways, the conduits and the controlling appliances in these works form a distinct class in the range of dock machinery, and as such will furnish themes for discussion in this chapter and in the chapters by which it will be immediately followed.

The primitive sluice or "shuttle," as it was termed by the original canal builders, governed the hydraulic flow through a connection between the levels of water above and below the lock, and took the form of a square orifice in the panelling of the gate itself. The orifice was fitted with and was completed by a frame in which a movable paddle was raised or lowered as was desired for the opening or closing of the sluice, by means of a cast iron rack which was attached to a vertical spear. It was operated by spur gearing of the style affected by the old millwrights to whom the

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devoir of acknowledgment and of the recognition of their sources has already been paid in this manual, and who, like the Marines in His Majesty's Navy, each and all combined the skill of several crafts in one capable personality, and wrought both in wood and in iron—with results such that their methods and their works still have for men who are old enough to remember the last survivors of their class, a charm which is peculiarly their own.

The original gate paddles, modernized in design and in materials of construction, are still employed in such special cases as those of the gates of the entrances to dry docks, where the paddles are used for filling the dock with water from a bordering river or an adjoining wet dock, whether for the purpose of enabling a ship to float in for repairs or to float out when these repairs are completed. A modern type of gate paddle for filling a dry dock with water is illustrated in Figs. 55 and 56.

In almost, if not in all, other circumstances the practice now is to connect the different levels together by means of conduits, which in the majority of instances are formed through the adjacent walls or piers and are built of masonry, brickwork, or concrete, but which in some recent examples of considerable importance have been laid in the bottom of the lock or entrance, and have been constructed in pipe form and of wrought iron, or of steel of strength sufficient to withstand the internal pressure to which they are subjected by the load due to the differential head of water under which they work, and under the influence of which the levels are regulated.

The substitution of the stone-built conduits in and through the walls of the lock or of the dock entrance for the orifice in the gates, was the first step in advance which was taken by British engineers as the dimensions of the locks grew greater, and as greater despatch was required in the process of raising or lowering the levels in the locks. The effect of the shock and vibration due to the continual working of the paddles was found to be injurious on the light timber-built gates of the day, an injurious effect which with enlarged sizes was naturally increased in geometrical ratio. The flow of the passing water was therefore transferred from the gate to the solid walls on each side of the lock, and, as was inevitable, the design for the paddles was transferred at the same time in almost all the details of that design, the only change made being the substitution

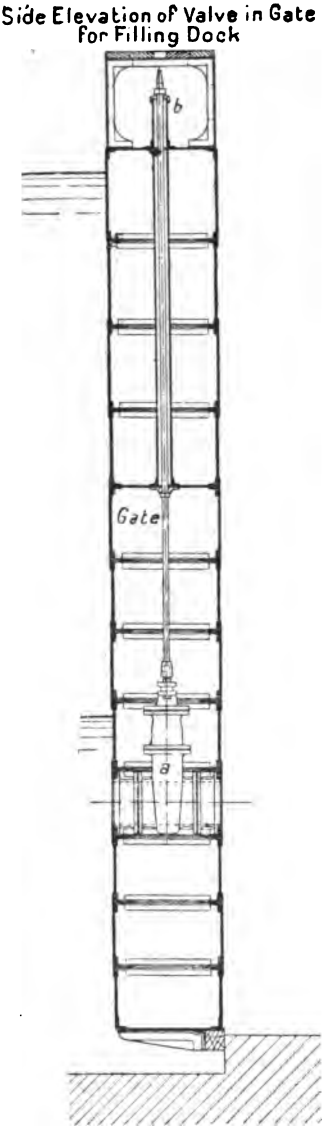

Fig. 55.
SLUICE VALVE FOR DRY DOCK.

a Sluice valve. *b* Operating gear.

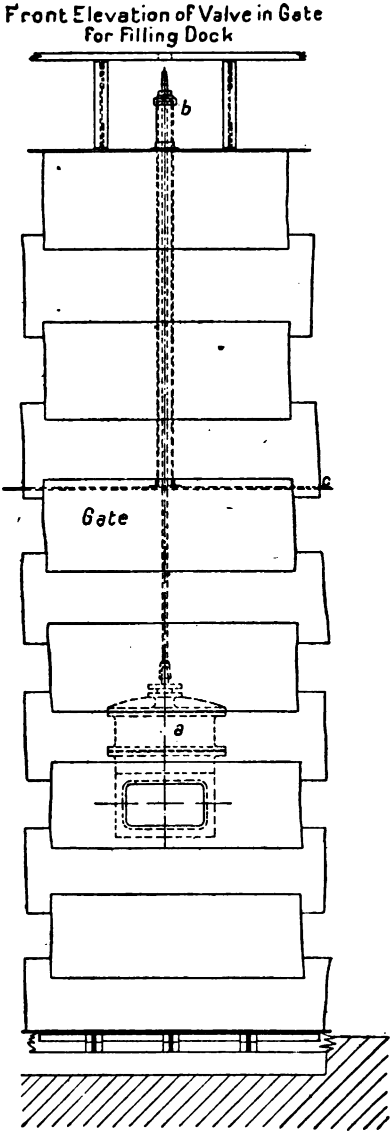

Fig. 56.
SLUICE VALVE FOR DRY DOCK.

a Sluice valve. *b* Operating gear.
c Watertight deck.

of grooves in the stonework for the timber frames which were secured to the gates and in which the wooden paddles were moved up and down. That was the form of sluice which in a day of mechanical small things was transferred from the gate to the conduit, and that is the form which some engineers advocate now, even though the first half of the first quarter of the twentieth century has more than passed away, and has left in its wake the tale of the splendid engineering achievements of the great nineteenth century.

Few combinations of material can be less suitable for use in any case in which sliding friction is the dominating feature of the movement than stone and timber, whatever be the nature of the stone or the species of the timber employed; and particularly is this so in cases in which the frictional resistance is intensified by adhesion and by the pressure due to a considerable head of water. In that case the seizing of the grain in the timber on the inequalities in the stone faces and on the joints in the stonework, leads to an expenditure of power for the starting of the sluice which may be described as excessive when required for the casual filling of a dry dock, which becomes more excessive when it forms part of the comparatively infrequent operation required for the regulation of level in the entrance to a tidal basin or dock; but which becomes a serious waste of energy when used in the working of a lock or of a navigation in which the movement is required many times in the course of a day. Further, the seizing and the load and the violence of the force required to move the sluice, have a prejudicial effect upon the stonework in the dressed faces, upon which the timber framing of the sluice bears, as the arrises of the horizontal joints between the stones are torn away under the upward movement, an effect which increases as time goes on with cumulative force, and for which it is difficult to find an effective remedy at any reasonable cost.

This difficulty was experienced and the cause of it was recognized many years ago, and an attempt was made to meet it in some degree by forming the bearing surfaces of sluices of metallic substances of various descriptions, such as cast iron, or brass, or gun-metal, or other similar alloy, the bearing surfaces being planed and closely fitted together. An improvement was effected by the use of this device, but the first cost was by no means inconsiderable, and the bearing faces wore rapidly owing to the scouring action of the materials, such as silt and fine sand, which are usually carried in suspension by the waters of rivers and estuarial indents during the periods of land floods in the rivers, and of maritime tides in the estuaries; these found a lodgment between the bearing surfaces when closing the sluice, the waters being in a state of equilibrium, and deposit of the materials in suspension (as a consequence of quiescence) continually taking place. The frequent combination of cast iron with copper alloy of one class or another in sluice construction led to another source of deterioration, an action which is now known as that of electrolysis, and through which much that occurred in that period in question may be explained to-day, but which fifty years ago was neither understood nor recognized except by a few such as the late Professor Faraday, and those who were then working with him.

The difficulties which are inherent in sluice construction have been acknowledged and appreciated by one generation of engineers after another, and the efforts which have been made to overcome these difficulties, and the designs and models of sluices which have been prepared with this intention in view, might without exaggeration be described as countless. Certainly they are not worth recounting, yet the engineering world waits for a type of lock sluice which will be reliable, moderately economical, and suitable for the purposes which the sluice is required to fulfil. It may be that the quest has been on wrong lines, that engineers who are all fallible men, are like others liable to be misled by the "tradition of the elders"—a tradition which in the case which is in point, found an exemplification in the prototype of the sluice, i.e. the paddle in the gate—and that the ultimate solution of the old problem with regard to the regulation and control of the levels of the water in maritime gateways, will be discovered in another direction altogether.

Some of the earlier efforts to get over the outstanding difficulties in the paddle type of sluice, due to the effort required to start the sluice from rest when the bearing surfaces had seized under the stress due to hydrostatic load, naturally enough took the form of the application of valves of the butterfly pattern for the control of the flow in the conduits in the side walls of the entrances and locks; by this device all difficulties inherent in the vertical lift were avoided, and a quarter turn sufficed for the full opening of the sluice-way. But that quarter turn had to be taken on a vertical shaft, of which the lower end necessarily worked in a footstep, and it was soon discovered that the rush of water through the conduit led in the nature of things to a rush of water-borne sand and silt through the sluiceway, that these materials penetrated into every crevice, found a lodging place in every available aperture in the bottom of the sluiceway, and speedily filled the working spaces between the foot of the shaft and the bearing in which it revolved in a manner so complete that—to quote the words of one who had had much experience in working this butterfly valve type of sluice, both in the East and in the West—"an elephant could not move the sluice." The result of this and of other defects which need not be laboured here, was that the butterfly valve pattern of sluice was abandoned and is now almost extinct.

Another method of avoiding the necessity for vertical lift in a sluice also avoided the difficulties which were inseparable from the use of the vertical shaft by placing the shaft in a horizontal position, and making the quarter turn for the complete opening of the orifice horizontally also. Sluices of this pattern have been in satisfactory use on the locks on the Aire and Calder Navigation* for many years and are still employed in these locks. The locks on that Navigation are of moderate dimensions—their length and breadth being 206 feet and 18 feet respectively—but the culverts in the lock walls are by no means of small size, as they are 5 feet in width and 7 feet in height, and, being rectangular, have consequently an area of 35 square feet. Fig. 57 shows a cross-section of one of these sluices, and Fig. 58 a front elevation. The sluice has a cast iron frame, and the upper and lower limbs of the frame are sheathed with timber on the down-stream and up-stream sides as required. These sheathings close against the faces of the cast iron bearing frame of the sluice, which is securely bolted to the masonry in the sluice shaft and in the line of the conduit. The axis on which the sluice turns is fixed well above the floor of the

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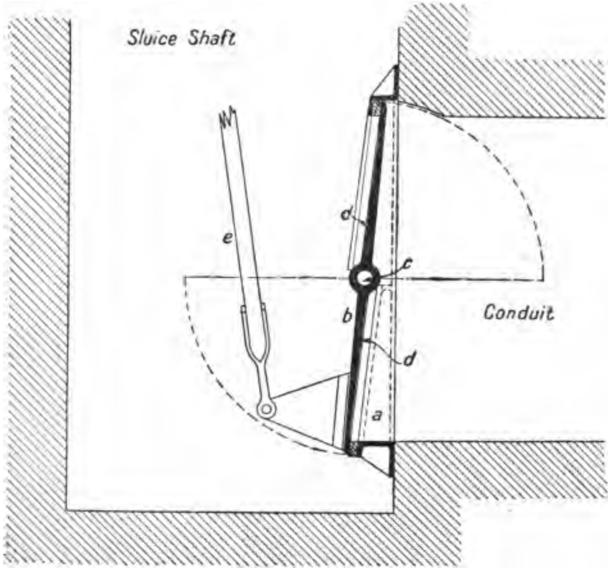
* The Aire and Calder Navigation is situated in the West Riding of Yorkshire, and in conjunction with the Leeds and Liverpool Canal forms a trans-islandic route for barge traffic, from the Mersey on the west, to the Humber on the east coast of England. The locks are 201–339 feet in length and 18–22½ feet in width.



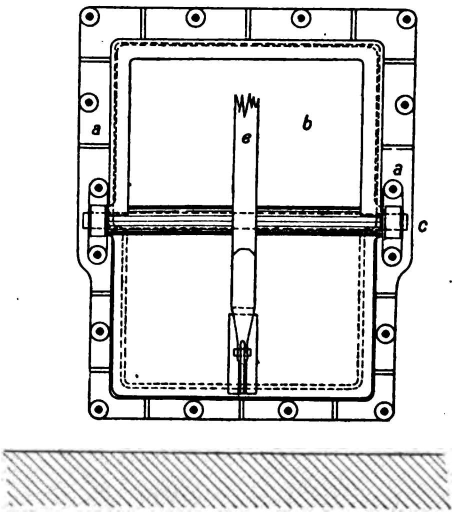


FIG. 57. LOCK SLUICES, AIRE AND CALDER NAVIGATION.

Cross-section of sluice for regulation of water level.

a Cast iron framing of sluice.
b Cast iron body of sluice.
c Horizontal shaft.
d Packing strips.
e Connecting spar to operating gear.

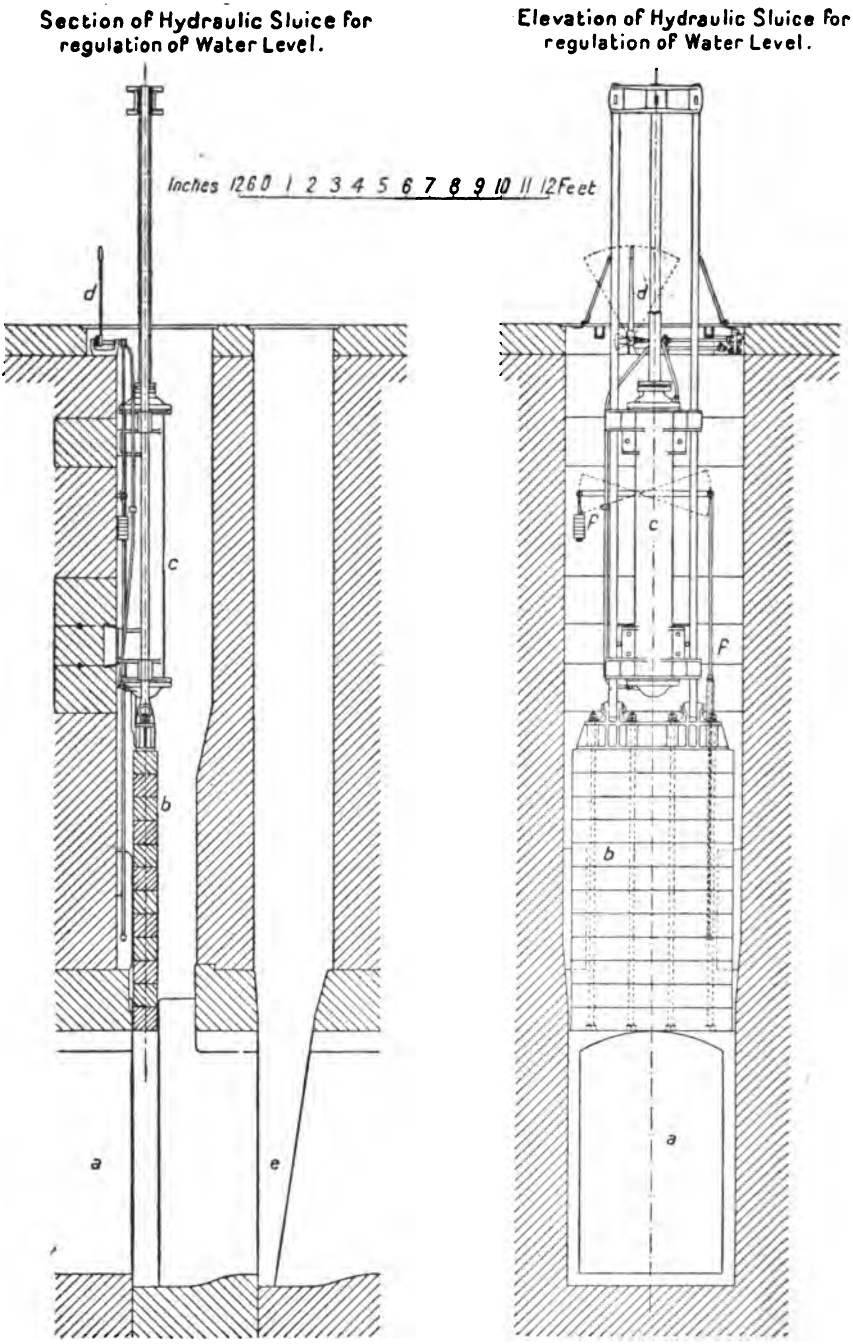
FIG. 58. LOCK SLUICES, AIRE AND CALDER NAVIGATION.

Front elevation of sluice for regulation of water level.

a Cast iron framing of sluice.
b Cast iron body of sluice.
c Horizontal shaft.
e Connecting spar to operating gear.

culvert and is therefore out of the reach of the heavier materials which are rolled along that floor by the water, so that the particular difficulties experienced in sluices with vertical axles and footstep bearings have not been encountered in sluices with horizontal axles and horizontal movement. The type of gear which has been found to be the most satisfactory for the operation of these sluices is shown in part in Fig. 57. The gear consists of (*a*) a bracket, which is attached to the lower end of the sluice door; (*b*) a spear, which is connected with the bracket by a pin and which is fitted with a rack at its upper end; (*c*) a pinion, the teeth of which engage with those in the rack and which is driven by worm gear. It is claimed that when the two limbs of the sluice are properly proportioned and the gear is clean, two or three turns at starting suffice to furnish impetus enough to compel the sluice to open or to close itself as the case may be, and that one man works the sluices and fills the lock (the fall being 7 feet) in 104 seconds, emptying it in 111 seconds. This type of sluice has well marked advantages for small locks, sliding friction is eliminated, movement is at once facilitated and restricted, and wear is reduced to a minimum; but it has also serious disadvantages which render the sluice unsuitable for any position in which such an abundant supply of water is not available as will render loss of water through leakage immaterial, as the pressure upon the sluice door which acts in such manner as to tighten the bearing of the sluice against the cast iron frame and thus to prevent leakage in the upper limb, operates in an exactly opposite direction on the lower limb, so that any tightening of the bearing part of the limb against the frame must of necessity be effected by means of pressure induced by movement of the operating gear—a very undesirable method of preventing leakage. Notwithstanding these defects this type of sluice has possibilities of improvement and of development, and should not be entirely overlooked.

Figs. 59 and 60 show sluices of what may be described as the traditionary pattern, but which are operated by the Armstrong hydraulic machinery. These sluices were constructed at Elswick, in 1878, for the new Dock Works at the North End of Liverpool, which were then in course of construction. They are required to work from time to time under a differential head of water of 30 feet. The sluice gates themselves are formed of solid beams of green-


Section of Hydraulic Sluice for regulation of Water Level.
Elevation of Hydraulic Sluice for regulation of Water Level.
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet
d
c
b
a
e
d
f
c
f
b
a

Figs. 59 and 60. Sluices at Liverpool Docks (North End).
Elevation of hydraulic Sluice for regulation of water level.

a Conduit. *b* Sluice. *c* Hydraulic cylinder.
d Operating lever. *f* Automatic cut-off gear.
e Groove for Subsidiary Paddle.

heart timber, the ends of which bear directly, without any intermediary and across the grain of the timber, against a face of polished granite masonry. No hand gear was supplied with these sluices, as in the event of a breakdown of the hydraulic machinery a subsidiary paddle, which was erected in a pit adjacent to each sluice (and which can be worked by hand power), can be substituted for the hydraulic sluice if and when required.

Another example of an Armstrong hydraulic sluice (or "shuttle" as it was described at Elswick) is presented in Figs. 61 and 62. These shuttles were erected at Her late Majesty's Dockyard at Chatham, and although they were earlier in actual date than those at the Liverpool Docks, which have just been described, having been constructed in the year 1870, they are of rather more modern design. In each of the Chatham shuttles the sluice gate is of cast iron instead of greenheart timber, and the bearing face against which it closes and on which it works is also of cast iron instead of granite masonry. Further, both the shuttle and the bearing face were protected by facings of brass or bronze, which were planed to a true surface and were interposed between the cast iron bodies of each shuttle and of its bearing, and undoubtedly did much to reduce the heavy sliding friction; but as the water in the River Medway at Chatham contains a proportion of salts in solution which differs very little from the proportion in sea water, the introduction of brass facings, useful as they were, carried with it a peril of the formation of a galvanic pile which, although of low power, involved danger of damage through electrolytic action. The arrangement of the hydraulic machinery for the operation of the shuttles differs from that employed at the Liverpool sluices, as owing to the limited depth from the surface of the ground to the conduit controlled by the shuttles the hydraulic cylinder was laid horizontally under the ground instead of being fixed vertically to the side of the sluice shaft. This arrangement necessitated the introduction of the linked chain and of the guide pulley therefor, which are shown on both the illustrations, and further rendered it necessary to load the shuttle with balance weights in order to overcome the inertia and the frictional resistance of the shuttle when it was required to lower it at any time, and to ensure its automatic closing when required.

Both the Liverpool and the Chatham types of sluices have the

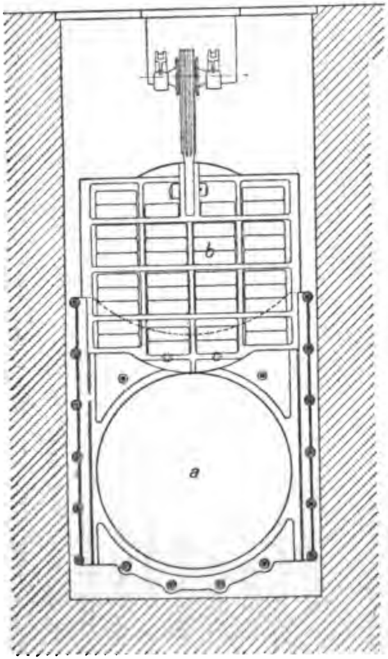


Fig. 61. Sluices at Chatham Dockyard.

Elevation of hydraulic shuttle for regulation of water level.

a Conduit. *b* Shuttle.

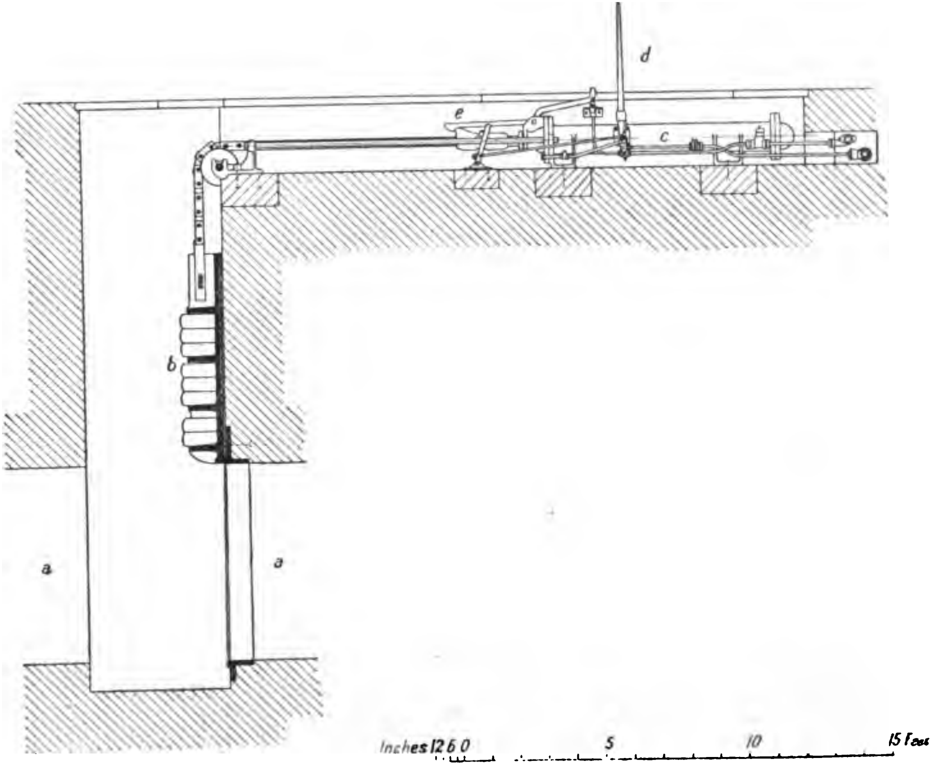


Fig. 62. Shuttles at Chatham Dockyard.

Section of hydraulic shuttle for regulation of water level.

a Conduit. *b* Shuttle. *c* Hydraulic cylinder.
d Operating lever. *e* *Automatic* cut-off gear.

merit of simplicity, and will probably in most cases have a measure of water tightness; and in such instances as those in which the sluices are only required (1) to withstand pressure upon one side, and (2) to be occasionally moved, they have many points in their favour for positions in which ample hydraulic power can be commanded, and where the necessity for reducing working expenses to a minimum level is not paramount.

Difficulties of the same sort as those which have been considered here, and which arose from the same causes, were experienced in the case of the relief valves from reservoirs for water supply, valves which were in some cases required to work under considerable head. About the middle of the nineteenth century an attempt was made to remove these difficulties by the introduction of valves of cylindrical form, which were worked under conditions of equilibrium so far as the pressure of the water upon the valve was concerned, and through which the discharge was effected by the lifting of the valve from its seat, as in the case of an ordinary safety valve on a boiler, the difference between the two being that whereas in the safety valve the flow of the steam is upward, in the relief valve the flow is downward.

A little later, that is to say about the year 1870, the same principle was applied to lock sluices for the first time. Fig. 63 and Fig. 64 show the method which was finally employed and the manner in which the principle was applied. It will be observed that the weight of the cylinder was balanced in such manner that the operation of each sluice was brought well within the power of a single man, as was necessary seeing that it was required that the sluices should be opened and closed many times a day.

In the cylindrical sluices as originally designed and constructed, the arrangement of the balance weights was much neater and more compact than that shown on the illustrations, while the form of the working gear was, from a theoretical point of view, more mechanically correct than the present form. In these sluices the balance weights with their chains and the guiding sheaves therefor were disposed *within* the circumference of the cylinder of each sluice, and the working gear consisted of a short rack and pinion arranged in such manner that rolling instead of sliding friction obtained throughout the whole machine. But expediency demanded

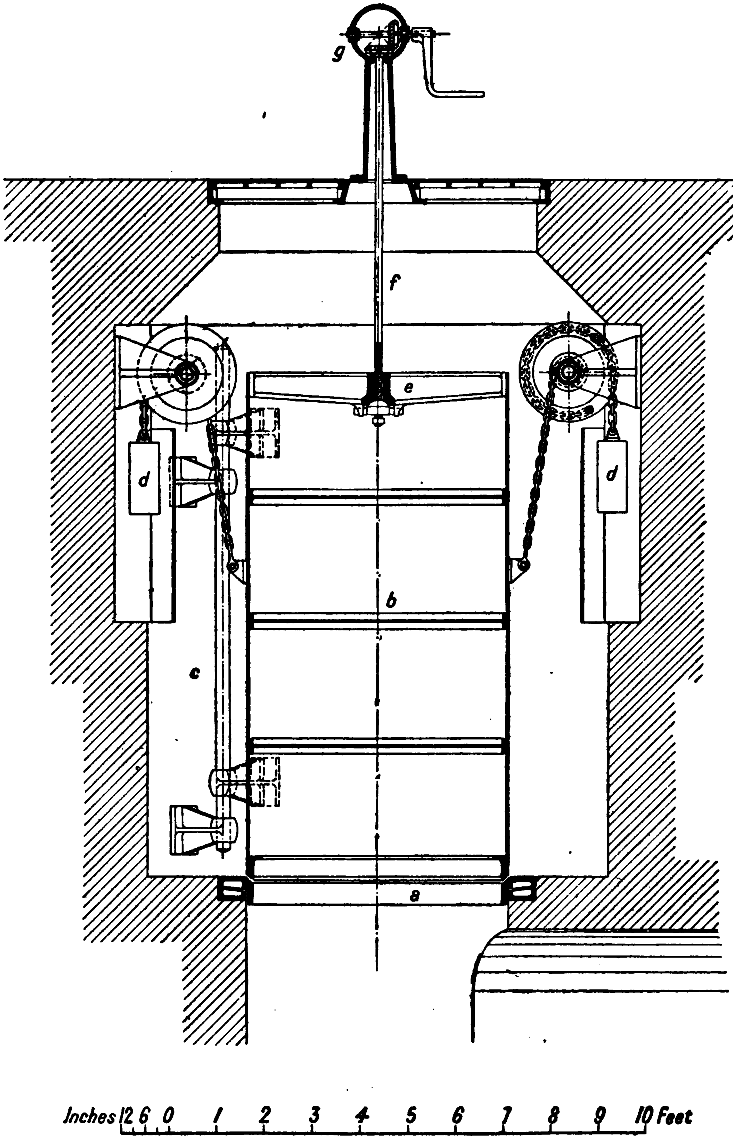


FIG. 63. LOCK SLUICES ON WEAVER NAVIGATION.

Cross section of cylindrical sluice for regulation of water level.

b Wrought iron cylinder.
a Cast iron seat for sluice.
c Guide.
g Operating gear.
e Crosshead.
d Balance weights.
f Lifting screw

that the alterations embodied in the illustrations should be effected, because experience revealed unlooked-for difficulties in the operation of the sluices. These difficulties will be described here, as it is more agreeable though less educative for a student to learn wisdom from the errors of his predecessors than from mistakes of his own; notwithstanding which fact there is much truth in the adage, that "a man who never makes a mistake never makes anything."

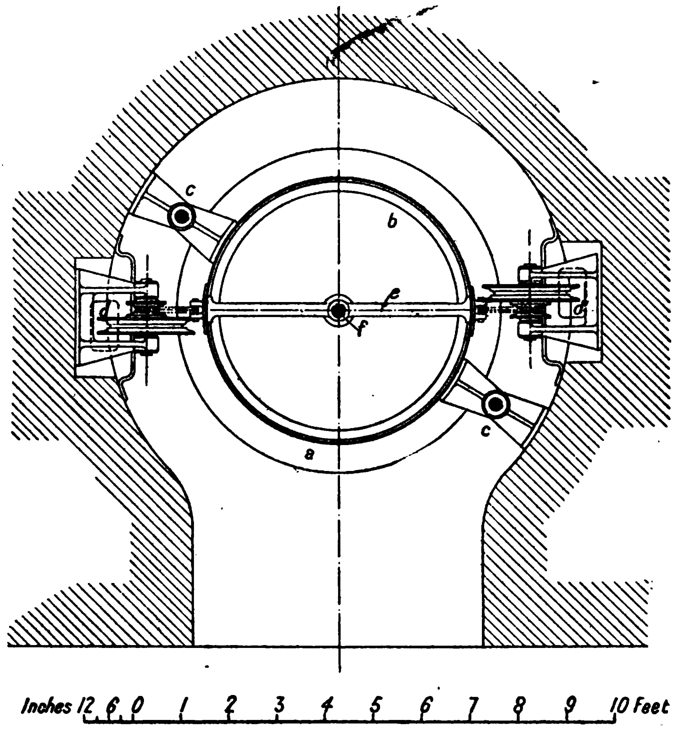


FIG. 64. LOCK SLUICES ON WEAVER NAVIGATION.

Sectional plan of cylindrical sluice for regulation of water level.

a Cast iron seat for sluice. *b* Wrought iron cylinder. *c* Guide.
d Balance weights. *e* Crosshead. *f* Lifting screw.

When the first of the locks which were fitted with sluices of the cylindrical type were completed, and the sluices themselves were brought into use, it was discovered that the value of the sluices was discounted by a serious and dangerous defect which was inherent in their design, their construction, and their manner of working. When a cylindrical valve was raised from its seat water rushed violently into the vertical shaft below the seat. This was the purpose for which the valve was constructed, and for which it was raised in working; but the water was drawn *from the surface*, with the result that together with the water great quantities of atmospheric air were also drawn into the vertical shaft and through this shaft into the horizontal conduit with which it was connected. As soon as (if indeed not before) hydraulic equilibrium was restored, gravity drove these masses of air to seek an outlet from the culverts through which they might find a way of return to the atmosphere from whence they had been so violently drawn. They found such outlet through the open, i.e. uncovered, cylinders of the sluices, roared through these cylinders like miniature hurricanes, lifted the balance weights as if they had been sheets of cork instead of cast iron, flung them down into the shafts below, and disconcerted in no ordinary measure the people who stood in proximity to the sluices, especially the astonished ladies who had come to witness the opening of the works, and who fled *instanter*, appalled by the noise and the commotion, and without any understanding of the simple cause of their terrors.

Apart from the roaring of the escaping air, which while it lasted was disagreeably insistent, the obvious danger was that of the displacement of the balance weights; but there was a concurrent danger less apparent at first and more serious as the disturbance of the weights led to the destruction of the equilibrium of the sluice system, sometimes quite of a temporary sort, at other times permanent until readjustment had been completed, which overcame the resistance of the operating gear, causing shock and rapid revolution of the handles which was dangerous in no ordinary degree to the attendant. On this account the mechanically correct rack and pinion were removed for safety's sake, and were replaced by the screw and nut shown. The special difficulties which were met with at the sluices themselves could have been got over in measure by the introduction, during construction, of air shafts in the horizontal lengths of the culverts; but that would only have removed the hurricane-like effects from one part of the quay of the lock to another, so that in any case the defect would have existed and the danger would have always been present; but the fact was that the possibility of the occurrence of the phenomena which followed the raising of the cylinders, had never been thought of by anyone concerned in the matter. Further difficulty was experienced in the wear of the tapered foot of the cylinder, and of the conical seat into which the foot was fitted, which were both formed of cast iron and were turned and bored, as the machined faces wasted under the scouring action of the water. This is not so serious a matter as the indraught of air, which of itself served to condemn the type of sluice as originally designed for lock purposes, with the result that for years the construction of lock sluices of the cylindrical valve type was abandoned. Yet the type remains, the principle is right, and can be usefully employed for sluices or valves of considerable dimensions. This is evidenced by the fact that an inverted syphon which was constructed in 1912 under the Colorado River (between the western American States of California and Arizona) as part of a great irrigation scheme on the Colorado Valley, is controlled on the Californian side by means of a steel-built cylindrical sluice which has a diameter of 21 feet. What, therefore, was required was improvement in design, through which such defects as those to which reference has been made in these pages may be eliminated.

That this view was taken by the designers of the locks on the Panama Canal is evident, for as Figs. 65 to 69 (inclusive) show, they adopted the cylindrical valve for a number of special sluices in the central piers of their great twin locks. It also seems to be evident that in the design of these sluices they followed the lead of some of the continental engineers, who had recognized the inherent defects in the original design and had set themselves to remove these defects by improvement in construction. The methods which were finally adopted on the Panama Canal are deeply interesting from an engineering point of view, and should be so valuable to students that they will be described here in some detail. But before describing the construction of the cylindrical valves it is necessary, for the sake of lucidity, that the circumstances under which the valves were employed should be briefly explained.

Certain of the twin locks in the flights or staircases at Gatun and Miraflores, as well as those in the single pair at Pedro Miguel, are divided into compartments, first, by intermediate gates, and secondly by guard gates which have been placed above the upper gates and below the lower gates. Five different pairs of gates have thus been erected in each of the locks in question, through which eight different lengths of lock are available if required for the passage of steamers. The main longitudinal conduits by means of which the lengths of each lock are filled and emptied are generally circular in section and are 18 feet in diameter. One of these main conduits has been formed in the concrete work of each side wall in the twin locks, and one, and one only, in the central pier which divides the pair of locks from each other. The fore and aft flow of water in the main conduits is controlled by vertical gate valves, to which reference will be made later; but owing to the fact that a single culvert only has been provided in the central pier for the supply and discharge of water to and from the two locks, it became necessary to provide subsidiary transverse culverts through which the flow from the main culvert could be diverted to the right hand or to the left as might be required for the passage of traffic through the one lock or the other; and also became necessary to control the passage of the diverted waters by means of special valves or sluices, each of which was required to be capable of sustaining pressure on both sides, and of being opened or closed independently of and apart from all other sluices. It was for these special sluices that it was decided to employ the cylindrical valves, the decision being important as it affected the equipment of the whole of the six pairs of locks.

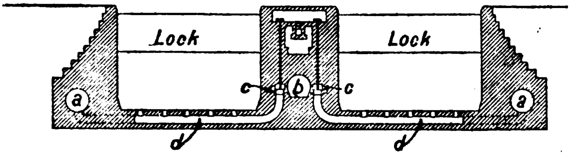


Fig. 65. Lock Sluices on Panama Canal.

Cross-section of pair of locks showing position of closed cylindrical sluices.

a a Conduits in side walls. *b* Conduit in central pier.
c c Cylindrical sluices. *d d* Subsidiary transverse culverts.

Fig. 65, which shows in outline a cross-section of a pair of locks on a line which passes through the centre of the subsidiary transverse culverts and of the special sluices which control them, will serve to illustrate the circumstances thus described, while Figs. 67, 68, and 69 show the method of construction adopted for the cylindrical valves. It will be seen from Fig. 67 that although the open type of cylinder has been maintained for the working part of the valve, the valve is operated by the movement of that cylinder in an encasing cylinder, either in an upward (or opening) or downward (or closing) direction. The encasing cylinder is placed above the working cylinder, is completely closed in by means of a domed cover, and is therefore cut off from all connection with the outer air. The water supply to the valves is drawn entirely from the central conduit, which conduit is itself fed by water which is drawn from the upper part of each lock through an intake, the sill of which is level with that of the floor of the lock. This intake is always completely submerged, with the result that any quantity of air which may be drawn in is so inconsiderable as to be negligible, and has no effect upon the working of the sluices. Further, it will be observed that steel construction has been abandoned, and that the working cylinder and the upper or encasing cylinder, with its domed cover, have all been constructed of cast iron. The valve or working cylinder of the sluice is suspended by means of a single rod in the centre and is not balanced. The cylinder is over 7 feet in diameter and has a stroke of 3 feet 1 inch; hence it was necessary to preserve the position of the working cylinder throughout the stroke by means of guides. Four guides were provided, each being built up of four lengths; the lower length is in each case cast in one with the seat of the valve, the central portion forms a part of each of the brackets which support the upper casing, while each upper portion is secured to the inner face of that upper casing. The casting which forms the seat of the valve and on which the foot of

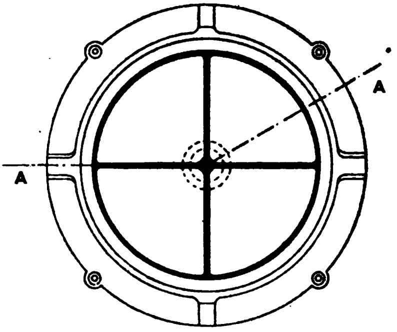


FIG. 66.
LOCK SLUICES ON PANAMA CANAL.
Sectional plan of closed cylindrical sluice, showing line on which section in Fig. 67 is taken.

the working cylinder makes the watertight joint, is trumpet mouth in shape, and the bearing therein on which the foot of the valve rests is indented in such manner that the momentum of the rushing waters will carry them across the indent, and so avoid any serious erosion on the bearing. This is an ingenious arrangement, is one which is likely to be effective, and is of no small interest and importance. It is shown in detail in Fig. 68, in which it should be

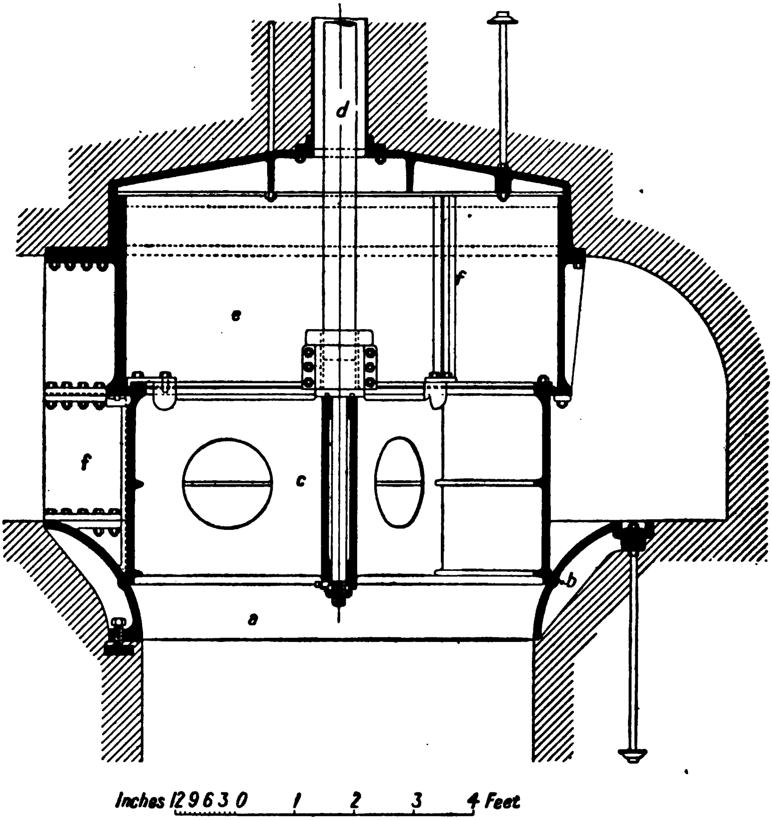


FIG. 67. LOCK SLUICES ON PANAMA CANAL.

Section of closed cylindrical sluice for regulation of water level, taken on line *AA* on Fig. 66.

a Trumpet shaped valve seat.
b Indent for bearing of cylinder.
c Working cylinder.
d Suspension rod.
e Encasing cylinder or drum.
f f Guides.

noted that the section is taken on the centre line of one of the guides to which reference has just been made. The opening which admits water from the conduit to the chamber which surrounds each cylinder is 13 feet wide and is 4 feet 6 inches high in the centre, the concentric portion thereof being 13 feet in diameter. The vertical shaft through which the waters flow away from the trumpet-mouthed orifice is 6 feet 6 inches in diameter; these special sluices are therefore known as the "78-inch cylindrical valves."

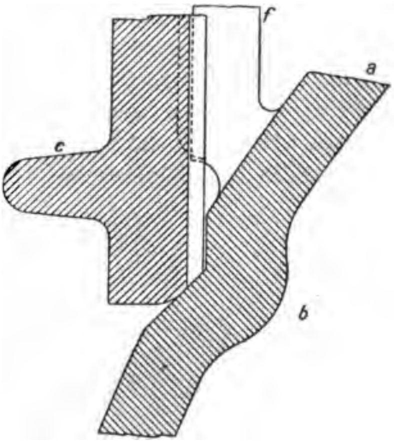


Fig. 68.
Lock Sluices on Panama Canal.

Detail of valve seat of closed cylindrical sluice, showing construction of indent.

a Trumpet shaped valve seat.
b Indent for bearing of cylinder.
c Working cylinder. *f* Guides.

In the working of the Panama Canal the whole of the supply of water for the passage of the great traffic which will eventually use the waterway, whether in times of peace or of war, will be drawn from the Chagres River. The watershed of this river is for the most part composed of wild and precipitous mountain districts, in which a rainfall of 2 inches per hour is a common occurrence in the wet season, while in the dry season the rainfall is confined to disconnected tropical showers, of which (owing to evaporation and to absorption by a vegetation of amazingly rapid growth) but a small proportion usually reaches the stream. It will therefore be readily understood that the Chagres varies from a turbulent torrent in times of heavy rainfall in the wet season, to a placid and gentle stream in the dry season when the supply available for the working of the locks will on many days fall below the actual quantities which will be required and used. Consequently it is contemplated that under the most favourable circumstances, the level of Gatun Lake will fall during the dry season; hence one of the essentials is that water should be economized in dry times, that there should be no waste, and therefore that leakage should be reduced to as nearly a minimum as is reasonably practicable.

For this reason it was considered necessary to take special precautions to make the joints between the working cylinder and the cylindrical casing as nearly watertight as was possible. Attention has already been drawn to the fact that the sluices are required to stand pressure in both directions, so that it was necessary that the watertight joints should be double acting. The method by which this has been effected is shown in detail on Fig. 69. The leather of which the flat concentric lift valves (which are plainly shown on the detail) were formed was, before being used, treated by immersion in a mixture of neat's foot oil and paraffin for three or four days in order to increase the pliability of the material, and to eliminate the danger of undue rigidity in the joint-making material interfering with the ready working of the valve.

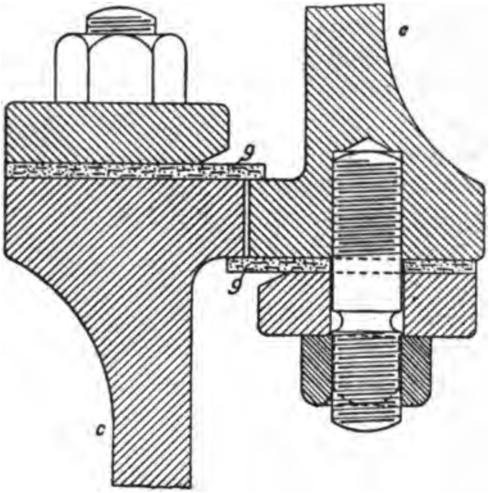


FIG. 69. LOCK SLUICES ON PANAMA CANAL.

Detail of joints in closed cylindrical Sluice, between working cylinder and cylindrical casing.

c Working cylinder. *e* Encasing cylinder or drum.

g g Leather lifting valves.

In the case of the Isthmian Canal, when discussing the various questions which relate to leakage, corrosion, etc., it is necessary first to realize, and then to remember, that all the water in the lake, the channels, and the locks, will be pure and fresh in quality, and is likely to continue in that condition, without pollution by sewage or by manufacturers' refuse; while such proportion of sea water as may find a way into the locks at Gatun and Miraflores will probably be found in time to be diluted to a degree sufficient to prevent injurious action on the metallic construction work which may be immersed, either permanently or from time to time, in the diluted solution of the sea salts. This observation is interposed here parenthetically, as the quality of the submerging waters has such an important bearing upon sluice design and construction, whether in the Isthmus of Panama or elsewhere.

In common with all the rest of the dock and lock machinery on the great Isthmian waterway, electric power is employed for the working of the cylindrical valves. We have already said that the working cylinder in each valve is operated by means of a single central rod. This rod is 2½ inches in diameter at the lower end, and is threaded through an elongated central boss which was cast with the cylinder, and which is connected therewith by four radial arms. The central boss acts as a sleeve or distance piece for the operating rod, and to it the rod is secured by means of a lock nut of special form. Above the central boss the solid rod is replaced by a steel tube in the upper end of which a nut is fixed. This nut engages with the screw by means of which the working cylinder is raised and lowered, and which was cut in the lower part of a second, or upper, solid rod or shaft, to the upper part of which shaft a manganese bronze sleeve is secured by a sliding key, which revolves (carrying the upper rod with it) on roller bearings on a flange which forms part of a cast iron pedestal through which the shaft passes. A bevelled wheel is secured to the lower end of the cast iron sleeve, and is driven by a bevelled pinion keyed on to the shaft of the electric motor by means of which the whole of the operating machinery for each sluice is driven. The upper end of the steel tube or valve stem (in which the nut is fixed) is passed through a stuffing box, so as to reduce to a minimum the infiltration of air from the atmosphere into the domed cylinder. The motor runs at the rate of 750 r.p.m., and is provided with a limit switch in order to avoid overrunning, as well as with a solenoid brake for the purpose of the intermediate stoppage of the motor spindle when the current is cut off. The tests which were made for the purpose of measuring the power used in the operation of the cylindrical valves, showed that some 7½ horse-power were required throughout the period of the opening of each valve. It is considered that at the very beginning of the opening 15 horse-power are required, this great power being expended in starting the rotation parts of the motor and in overcoming the inertia of the valve itself. For the closing of a working cylinder, current is required in order to start the motor, but after a start has been secured, gravity is, in the absence of balance gear, sufficient for the completion of the operation; in fact the current measurements made indicate that power is actually developed by the valve in the process of closing. The valves can be opened to their full extent in ten seconds in each case, and closed in about the same time.

CHAPTER VIII

SLUICES WORKING ON FREE ROLLERS, ON WHEELS AND AXLES, ETC.

Another method of overcoming the difficulties due to the seizing of bearing faces in sluice gates, and to the excessive power required to overcome (1) the breaking of the seal of the gate when starting from rest, and (2) the resistance due to the sliding friction of wood on stone—which, like an evil fate, pursued the sluice throughout its stroke—was suggested and patented more than forty years ago by the late Mr. F. G. M. Stoney. In this method the seizing of the surfaces and the resistance of the sliding friction involved in the movement, was got over by the introduction of a series of free rollers* between each working face, through which the sliding friction was converted into rolling friction. By this device the power required to start a sluice from rest, and to keep it in motion when started, was reduced in a remarkable degree,† and when this reduction was combined with a competent system of balancing the weight of the sluice by means of pendant counterweights slung from wire ropes, carried round overhead sheaves, and connected with the body of the sluice, the effort required for the operation of sluices for openings of 30 feet by 26 feet was brought within the capacity of two men of average muscular vigour.

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* By free rollers are meant rollers in which the load on each is carried on two opposite lines in the periphery, so that the travel of each roller is always half of that of the gate; as contrasted with wheels and axles in which the load is divided between the periphery, one side of which only is loaded, and the axle; and in which the travel of each wheel is equal to the stroke of the gate.

† The extent of the pull required to move the several roller sluices in the locks on the Panama Canal (a description of which will be found farther on in this chapter) was carefully measured by means of a dynamometer under circumstances which represented the extreme conditions of working at Gatun Locks; and was found to be about 3½ per cent of the load due, to the weight of the sluice and its accessories, and to the pressure on the sluice produced by the maximum head of water to which the sluice could be subjected.

It is claimed that one thousand sluices of this type have been used for flood discharge in various parts of the world, including *inter alia* the Panama Canal (where, as we have already hinted, great quantities of flood water have to be dealt with in the wet season), the Chicago Drainage Canal, the Thames at Richmond, the Manchester Ship Canal, the Clyde at Glasgow, the Nile at the Assouan Dam, the River Euphrates at Hindiah between the site of the ancient city of Babylon, and the confluence of the Euphrates with the Tigris, etc.

The first of these rolling sluices which were erected was made for sluiceways with a width of 20 feet in the clear. They were soon increased to 30 feet and subsequently to 50 feet, and even to 80 feet in width.

For the purpose of conciliating critical purists, it may be admitted that, strictly speaking, flood sluices are outside the scope of a manual relating to dock and lock machinery, and the questions relating to them will not be pursued further at this point; but some allusion to their use seemed to be required in order to indicate the extent to which the free roller type of sluice had been employed for the control of the levels of water in great engineering works at widely scattered parts of the earth. Not only so, but in addition to the flood gates referred to, roller sluices were designed and erected in 1888 for the control and regulation of water levels in what we have described as maritime doorways; the principal differences between the flood sluices and the lock sluices being first, that the width of the sluiceway in the latter is generally less than in the former, and secondly, that the character of the opening is altered, the opening in a flood sluice being (except indeed in dams and barrages) notch shaped; while in a regulating sluice in a lock or entrance the form is that of a submerged orifice.

Roller sluices as applied to the regulation of water levels in locks have been constructed of steel in every case and in all their parts (with the exception of the free rollers themselves, which have usually been made of chilled cast iron), and experience has shown that for such construction, while steel (or preferably pure wrought iron of the Low Moor or Bowling class) may be hoped to have a life of forty or fifty years in clean water, it can hardly be expected to survive for more than half that time in waters which have been contaminated by effluents from sewage works; this is particularly so in manufacturing districts, where the effects of the contamination are so frequently intensified by the action of fluids discharged from chemical works and from factories in which the processes of manufacture involve the continuous use of chemical products, or in a mixture of contaminated land waters with sea waters.

Following upon this observation designers of sluices and valves for dock entrances and for locks should be warned never to lose sight of, or to fail to provide against, a peril which is always present and always instant in the submerged and, therefore, unseen positions of these works. The peril is that of injury, even of destruction, which arises from the combination of CORROSION and EROSION,* that is to say, the combination of chemical effect with mechanical action, to which steel and iron work in sluices are in the nature of things, subjected in so intense a degree. When exposed to the influence of a moist atmosphere, or submerged in water, a film on the surface of the iron is oxidized, and is thus converted into a metallic salt—an oxide of iron. In iron work which is entirely submerged in still water the oxidizing process is a slow one, and depends largely upon the comparative quantities of free oxygen in the water. This oxidation is accelerated when, as in the case of a sluice, the water is set in violent motion from time to time, since the scouring power of the rapidly flowing water erodes the oxidized coating which has been formed on the surfaces of the iron work, and leaves these unprotected surfaces in such condition that further oxidization, further rusting, further corrosion, takes place in the next period of stillness. The process is not a rapid one; it is slow, but it is as sure as it is slow, and its effects upon the structural iron work of a sluice become very manifest in process of time. For the sake of emphasis and with the purpose of leaving impress upon the mind and memory of the student, the warning is repeated that in sluice design and operation it is the danger due to the combination of corrosive effect and erosive action which is to be dreaded and is to be provided against; if apology for the repetition be needed, it will be found in the fact that this peculiar difficulty, which is inseparable from the use of iron or steel in sluice construction, seems to have remained so entirely unnoticed and unheeded by engineers and in engineering literature that no beacon light appears to have been erected on so dangerous a shoal, or, in other words, that no warning as to the existence of so grave a peril, or counsel as to the course which should be taken for its avoidance, appears to have found a place in any engineering textbook which has been published in the United Kingdom. Even if this statement be erroneous, and may be proved by a joyful critic to have been made here (like Dr. Johnson's lexicographical definition of the pastern of a horse) through ignorance, it is hoped that it will be of service to the student in calling his attention to the neglected work in which the warning was offered, and in giving that classic a new value in his eyes.

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* This is amply borne out by a Report issued by the Panama Canal Authorities which is added as an Appendix, p. 193.

We have already dwelt upon the fact that in the older and more crude forms of sluice doors and gates the contact between the faces of the sluice bearings and of the sluice doors under pressure was relied upon to reduce leakage to a minimum. It is obvious that the more effectively such method was carried out, the more difficult it became to work the sluice and the greater the expenditure of power which was required for such working. On the other hand, it is equally obvious that the interposition of trains of rollers between the bearing faces completely destroyed the old methods of avoiding leakage, and made it absolutely necessary that new methods should be introduced. In the first of the roller sluices which were erected for flood discharge purposes, this difficulty was got over to some extent by making the door and the groove therefor wedge shaped, by constructing bearing surfaces on the back (or up-stream side) of the door and on the back of the groove, and by trusting to the weight of or of pressure upon the door to form a watertight joint through the contact of these bearing surfaces. The difficulty about the arrangement was obviously that if and when the downward pressure proved to be sufficient to stop leakage under any considerable head of water, the value of the rollers to facilitate movement and to save power was diminished in proportion to the diminution of the leakage, and consequently that the effort to raise the sluice from rest was almost as excessive as ever, the rollers being of little assistance except during the period of the stroke of the sluice after the gate had once been started on its upward way. The method was therefore only partially successful in the case of flood sluices, and was never applied to lock sluices.

In the design of the lock sluices of the roller type, the principle which was relied upon for the watertightness of the joints may be described generally as that of extreme accuracy of workmanship, such as has been rendered possible by modern methods of manufacture and by steel construction. First, the curved sill upon which each sluice rested was bored out accurately in a boring mill, then the foot of the steel plating of which the back of the sluice was formed was turned to fit the sill (curved construction in sluice work is a great mistake and should always be avoided), then an angle ledge was riveted to the head of the sluice door, which ledge bore upon a recessed seat provided therefor in the sluice frame, the bearing faces of both ledge and seat being accurately planed and fitted together in such manner as to come into contact at the same moment as that at which the lower edge of the door made its joint with the steel sill. The joints at the foot and head of the sluice being thus made, the sides were fitted with "stanching rods" which were made of steel tubes and which were hung from the door in such a manner that they rose when the door was lifted, and yet had sufficient flexibility to permit of their being forced by the pressure of the water into the re-entrant angles formed by the vertical bearing strips which were riveted at each edge of the door, and by corresponding strips at right angles thereto secured to each side of the sluiceway. It was anticipated that the circumferential contact between the rods and the bearing strips therefor would be sufficient to stanch the flow at the sides of the sluices so far as to render the leakage at the sides of the sluices negligible in quantity; but the anticipation was not realized, the stanching rods proved to be not only inefficient, but a positive source of peril in the working of the sluices, and were ultimately removed in the interest of safety.

The operation of the sluices showed as time went on that no workmanship, however accurate, can be relied upon to prevent some leakage in lock sluices which work under considerable heads of water. While the sluices were new the leakage was inconsiderable, and from the point of view of loss of water was without importance; but it was there, it existed, and because it existed it was bound to increase. The proverb has it that continual dropping wears away a stone, however hard that stone may be; and in like manner the continual attrition of even a slight leak under the impelling force of a considerable head of water will wear hard steel away, and so doing will increase the size of the orifice though it originally be infinitesimal in extent, through which the water escapes. Increase in orifice again leads to increase in flow, the effect is cumulative, the injury is progressive, and sooner or later will become destructive, even apart from the acceleration due to the failure of the stanching rods in the actual cases under consideration. The conclusion that in steel sluices accuracy of workmanship cannot be relied upon to prevent either initial leakage or ultimate destruction is therefore inevitable.

Experience in the working of roller sluices has further shown that in examples in which the gates are required to be frequently moved the effect of the travel of the free rollers, as they pass up and down in the grooves provided for them, becomes damaging to an extent which was altogether unsuspected. The grooves in question were lined with cast iron, the linings were of suitable design, of solid construction, and were secured to the masonry, concrete, and brickwork in which they were embedded in a thoroughly reliable manner. Yet under the combined influence of actual surface wear and of corrosion and erosion, the massive castings were worn through, in some parts nearly, in other parts entirely, in less than a quarter of a century.

The extent to which the contaminated waters, in which the particular roller sluices referred to worked, contributed to the unsatisfactory results which were experienced in their working, may perhaps be ascertained by a comparison of these results with those which will be arrived at, when sufficient length of time has elapsed to test the effect of the clean water working on the roller sluices in the locks on the Panama Canal.

CHAPTER IX

ROLLER SLUICES ON THE PANAMA CANAL

THE method of construction adopted on the roller sluices in the Panama Canal locks is shown on Figs. 70 to 77 (inclusive). The sluices are, in the main, constructed of nickel steel. The gates which control the conduits in the side walls (to which conduits reference has already been made, and which are, except at the chambers where the sluices were erected, circular in section and 18 feet in diameter) are fixed and operated in pairs. Figs. 70 and 71 show the manner in which the sluice chambers in the conduits were built. The chambers are in each case 20 feet 3 inches in width over all, and are 18 feet in height. They are divided into two by means of a midfeather which has in each case a thickness of 4 feet 3 inches. The effective area of each sluiceway is, therefore, 8 feet by 18 feet, or 144 square feet, consequently the area at each sluice

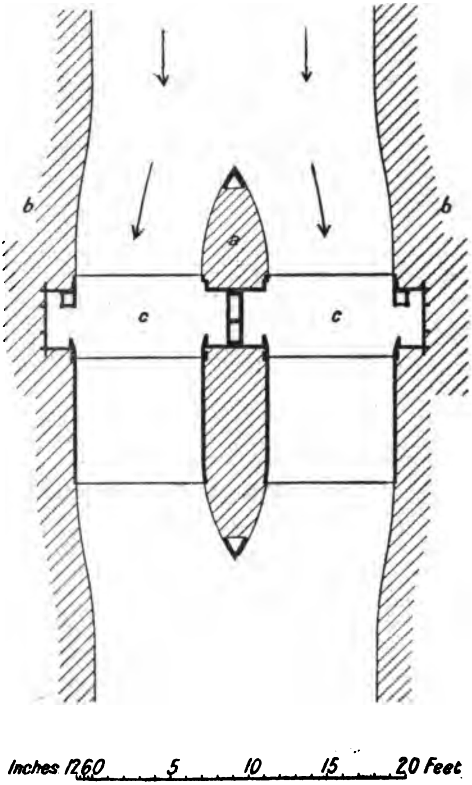

FIG. 70. LOCK SLUICES ON PANAMA CANAL.
Sectional plan of chamber for roller sluices.
a Midfeather. *b b* Side walls. *c c* Sluiceways.

chamber is 288 square feet as compared with the area of the 18 feet circular conduit which is nearly 255 feet. Each gate in each of the pairs referred to is rectangular in form, curves having been wisely avoided throughout, and is 10 feet 7 inches in width by 18 feet 10 inches in height. The gates have a lift of 18 feet, which corresponds with the diameter of the conduits, and a possible working head (for which the gates were designed) of 60 feet, so that in addition to the dead weight of the sluice and of the operating machinery, the load under which the gate is to be moved is over 330 tons. Besides the control gates the conduits are protected at each end by a special set of three gates, fixed side by side, and of the same design and dimensions as the control gates. It will, therefore, be possible to exclude the water from any conduit, and to pump the conduit dry.

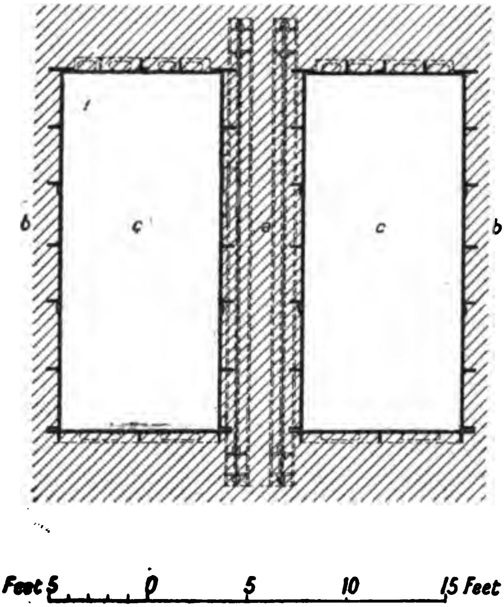

FIG. 71. LOCK SLUICES ON PANAMA CANAL.

Cross-section of chamber for roller sluices for regulation of water level.

a Midfeather. *b b* Side walls. *c c* Sluiceways.

The vertical and horizontal members of the framing of each sluice gate are formed of rolled joists of *H* section. Buckled plates are riveted to the flanges on the pressure side of these joists in such manner as to avoid projection beyond the line of the framing, and consequently in such manner that when under load the nickel steel in the buckled plates is subject to tensile and not to compressive stress. The shoe of each gate is formed of a steel casting accurately planed and fitted to a sill or "seal" which is formed of cast iron, is securely bolted down to the concrete work, and has a seat of babbitt-metal which is dovetailed into its surface for a length of the sill which is slightly in excess of the width of the gate. It will be seen that the watertightness or otherwise of the gate at the foot depends entirely upon the accuracy of the workmanship employed in the construction and erection of the shoe of the gate and of the sill upon which it bears, no material of a flexible or adjustable nature having been introduced between the two bearing surfaces. The watertight joint or "seal" at the head of the gate is formed by contact between a rubber bar which is bedded in and secured to a T-shaped casting; this casting is again bolted to the rolled joist which forms the uppermost horizontal member of the framing of the gate. The rubber bar makes a joint with the planed surface of the lip of an angle casting which is bolted to a cast iron lintel, which was carried across the sluice-way at a depth of 6 inches or 7 inches below the top of the sluice gate. A clearance of ¼-inch was left between the downward side of the T-casting which forms the support of the rubber bar and the planed lip of the angle casting, and this clearance represents the extent of the adjustment which, owing to the elasticity of the rubber in the joint, is possible as between the bearing surfaces of the lower or sill seal and of the upper or head seal in each case. At the sides of the gates continuous spring bearings were introduced in order to stanch these sides. The spring and the head which is supported by it are formed of bronze, and the particulars of the construction of the seal, which are somewhat complicated, are shown in detail on Fig. 76. The pressure of the waters on the spring and on the head which is secured thereto will in each case obviously tend to tighten the seal and thereby to reduce leakage, as the pressure on the spring and the gate will correspond in all positions during the operation of the gate; but it also seems to be obvious that the pressure on the curved nose of the head and of the planed bar against which it will bear will be considerable, will add to the power required to work the sluice, and will involve a corresponding measure of wear.

The roller sluices are raised and lowered by means of a valve stem which is connected at its lower end with the sluice gate by means of the bearings which were formed of steel castings and which are shown on Fig. 72. The upper end of the stem is secured to a crosshead which is supported by means of two vertical screws, one of which was erected at each end of the crosshead. These screws work through long nuts in which, and in the footsteps by which, their feet are supported, they revolve respectively. The screws are operated by means of a 50 h.p. electric motor which runs at 500 r.p.m. and drives a horizontal shaft by which two separate sets of bevel gear are again driven. The vertical screws are rotated by these sets of bevel gear, and in this way the crosshead is raised or lowered and the sluice with it. For the purpose for which the sluice gates and their accessories are being described in these pages, the details of the operating machinery are not of special importance, but it may be added that they are clearly shown in illustrations which were published in "Engineering,"* and which form part of a complete and detailed description of the works of the Isthmian Canal, which appeared in that Journal in the years 1912 and 1913.

A somewhat important feature in connection with the design and operation of the Panama Canal was, and is, that it was not necessary to make a serious attempt to reduce the consumption of the electric current which was provided, as owing to the great falls at the locks and to the fact that for the greater part of the year there is more than ample supply of water (a part of which will always be stored to make up for any lack in the dry season), the current is generated at a trifling cost by means of turbines which are driven by the water derived from Lake Gatun. For this reason the sluice gates were constructed without balance weights, as these weights would have complicated the work of construction and increased the difficulties of maintenance, without corresponding advantage except in the reduction of the consumption of current, which was hardly worth reducing as the cost per unit is so trivial. For this reason the only attempt to save power in the working of the Panama lock sluices was the conversion of sliding friction during the process of raising and lowering into rolling friction, by means

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* See "Engineering," Vol. XCV, p. 693.

of the interposition of the free rollers; the consideration referred to differentiates the case of the sluice working on the Panama Canal from sluice working in places in which the power, whether hydraulic or electric, is, at considerable cost, derived from the consumption of coal which has to be purchased and conveyed on to the site.

Sluice designers cannot afford to omit from their consideration the methods of construction adopted for the various types of sluices on the great trans-Isthmian waterway, nor to ignore the efforts which the Commission made on the advice of their engineers (who had collected the experience of the world in respect of the construction and of the working of large sluices), to grapple with the thorny problem of the provision of valves for the regulation of the levels of water in immense locks, such as those which the Commission was required by the Legislature of the United States to construct and to complete.

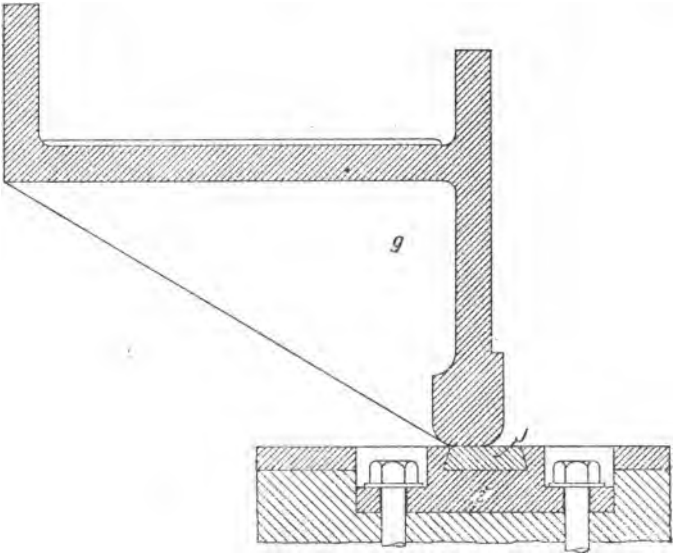

FIG. 75. LOCK SLUICES ON PANAMA CANAL.

Detail of shoe on roller sluice and of seal for bearing of shoe.

g Cast steel shoe. *i* Cast iron sill. *j* Babbitt-metal seal.

The Commission worked on a great scale; the dimensions of their control sluices are larger than those of any others which had previously been attempted, much less constructed on this earth; they had unlimited funds at their command; in the construction of their sluices they challenged not only the engineering world, but the elementary laws of Nature herself; and whatever the experience may be, which must be gained from the efforts which will be required for the maintenance of the sluices in the next quarter of a century, their designs will remain as classics in sluice construction, and must never be overlooked by sluice designers. The exceptionally pure character of the water with which they had to deal must, how-

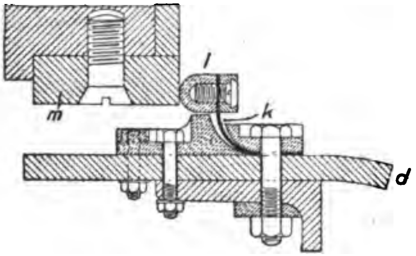

Fig. 76.
Lock Sluices on Panama Canal.

Details of arrangement for stanching leakage at sides of roller sluice.

d Sluice gate. *k* Bronze spring.
l Bronze seal. *m* Bearing strip.

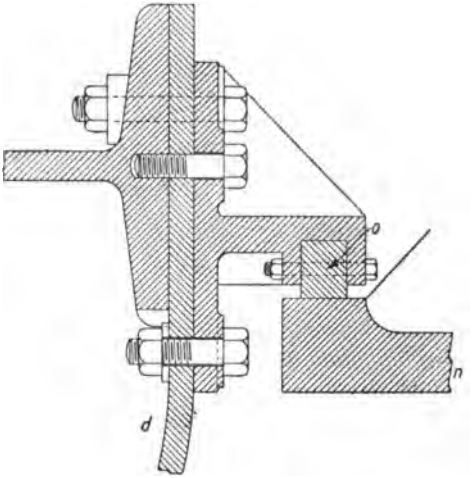

Fig. 77. Roller Sluices on Panama Canal.

Details of arrangement for stanching leakage at top of roller sluice.

d Sluice gate. *o* Indiarubber bar. *n* Lintel in sluiceway.

ever, be also kept in mind by such designers, as it does not follow that success achieved in the design of works which are to be operated in clean waters only, would be suitable for works on the seaboard, or works in manufacturing and industrial districts, or areas in which the population is really dense, in all of which the designer will be confronted with the inevitable effects of serious pollution of the waters in the rivers and streams as contrasted with the conditions of the rivers, streams, and impounded waters in the Isthmus of Panama.

CHAPTER X

WHEEL AND AXLE SLUICES ON THE NEW ERIE CANAL SYSTEM

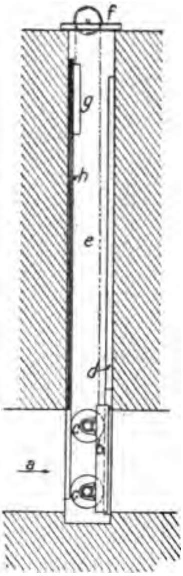

FIG. 78. LOCK SLUICES ON ERIE CANAL.

Diagram showing position of wheel and axle sluice.

a Conduit.
b Sluice gate.
c c Bearing wheels
d Guide rails for wheels.
e Sluice shaft.
f Chain wheel for balance weight.
g Balance weight.
h Guide for balance weight.

THE designs for the control sluices for the locks in the new Erie or Barge Canal in the State of New York, of which canal some description has already been given in preceding pages, embody certain original features and possess great interest for sluice designers and operators, particularly having regard to the extreme degree of accuracy of workmanship and of fit of the sluice valve or gate into its place, which was required owing to the method of stanching the leakage through the sluices which was adopted in the designs. The conduits in the side walls of most of the locks in the Barge Canal are rectangular in section, and have areas which vary from 35 to 63 square feet, the areas being roughly proportionate to the varying falls at the different locks. In like manner the dimensions vary, the width from 5 feet to 7 feet and the heights from 7 feet to 9 feet. The general arrangement of the sluices and the position of the sluice valve itself, as relative to the conduit and the particulars of the sluice shaft in each case, are shown in Fig. 78. Some of the details of the design of the larger sluices can be seen in Figs. 79, 80, and 81, while Fig. 82 shows the character of the plant for the generation of the electric current by which the sluices are raised and lowered. The sluice valves or gates are constructed of steel, With the exception of the lowermost of the horizontal members of the framing of the valves (which are of *H* section), both the horizontal and vertical members throughout are formed of rolled channels. The vertical posts at the sides of the gates are in each case built up of two channels, fixed back to back in such manner that a space of 2 inches intervenes between the webs of the channels; and in each gate six horizontal members are securely riveted to these verticals. The skeleton frame thus formed is covered on the face or down-stream side with a flat steel plate which is $\frac{9}{16}$-inch in thickness, and is riveted to the down-stream flanges of all the members of the framing, both vertical and horizontal. It follows from this arrangement of plating that the rivets by which the plate is secured to the framing are subjected to tensile stress when the load due to the pressure of the impounded water is carried by the gate. In the locks in the Barge Canal pressures due to differential heads of from 6 feet to 40·5 feet may be experienced, so

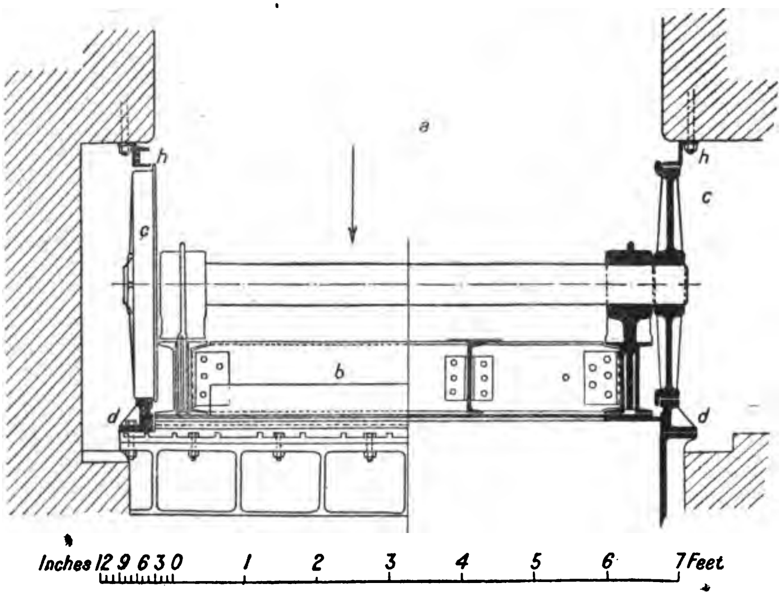

FIG. 79. LOCK SLUICES ON ERIE CANAL.

Sectional plan of wheel and axle sluice for regulating water level.

a Conduit. *b* Sluice gate. *c* Bearing wheels.
d Guide rails for wheels. *h* Guide for balance weight.

that in the case of the 63 feet valves the hydrostatic load due to the 40·5 feet head will be 71 tons, but it is possible that under special circumstances of level in the reaches of the canal, the head of 40·5 feet may be increased, for which reason the differential head adopted in the design of the sluices was 43·5 feet, representing a load of 76 tons. That load will be supported by four wheels which are formed of cast steel, are each 3 feet 2 inches in diameter over the tread, and are keyed in pairs to the ends of the two horizontal axles. The axles are 7 inches in diameter and revolve in journal

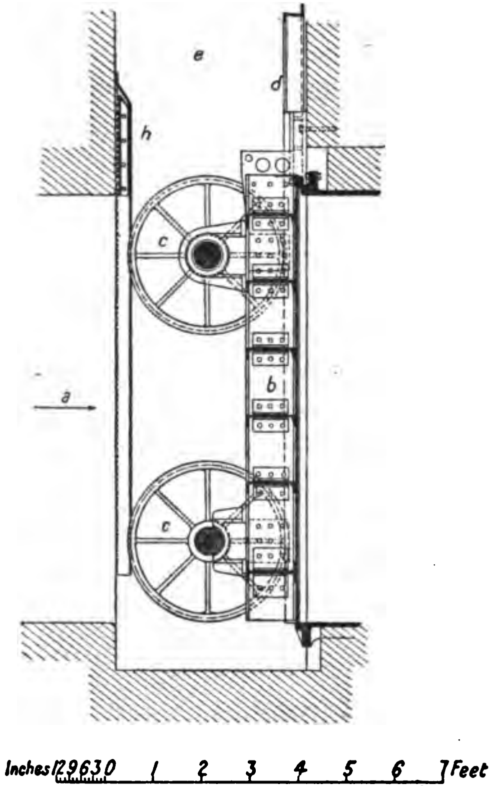

FIG. 80. LOCK SLUICES ON ERIE CANAL.

Sectional elevation of wheel and axle sluice for regulating water level.

a Conduit. *b* Sluice gate. *c* Bearing wheels.
d Guide rails for wheels. *e* Sluice shaft. *h* Guide for balance weight.

boxes which are of special construction, and are secured by means of turned bolts to the vertical side frames through projecting flanges or tongues which are fitted into the 2-inch spaces between the webs of the channels in the verticals already described.

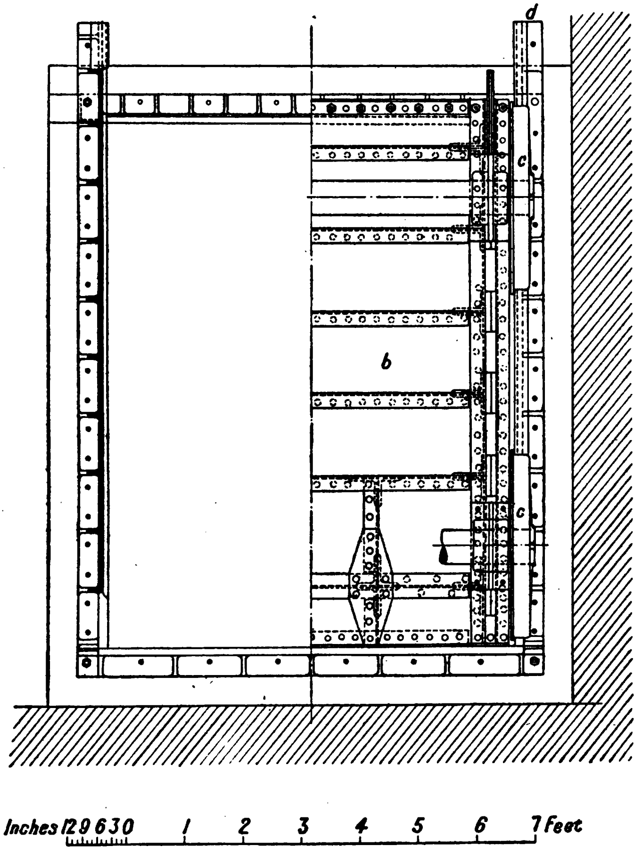

FIG. 81. LOCK SLUICES ON ERIE CANAL.

Sectional elevation of back of wheel and axle sluice.

b Sluice gate. *d* Guide rails for wheels. *c* Bearing wheels.

A cast iron frame formed of a sill piece, two side posts, and a lintel, is concreted into place at the mouth of the length of the conduit which the sluice gate controls. The sill on which the foot of the sluice actually forms a seal is bolted to the side of the sill piece of the cast iron frame. The sill is formed of cast steel, is angle-shaped in section, and is planed on its upper surface to a true horizontal line. From each end of the sill a side piece rises; each of the side pieces is formed of cast steel, and is also of angular section, but has as an addition to the angular section a bearing rail which was cast with the side piece and on the up-stream side thereof. The side pieces are both bolted to the respective side posts of the cast iron frame, and the inner side of each is planed to a true line, in such manner that the two together form a wedge frame with a minute taper thereon, a taper which is only ⅛-inch at each side, or ¼-inch in the total height of the gate which is 9 feet 5 inches over all; each gate is, therefore, 6 feet 11⅞ inches in width at the foot and 7 feet ⅛-inch at the head. The face of the bearing rail which was cast on each vertical angle piece was also planed, and the gate is maintained in its place by the wheels which travel up and down these bearing rails and which carry the load due to the water pressure. The system of cast steel angles by which the cast iron frame is faced on all sides, is completed by a cap which is bolted to the lintel of the framing. The bearing face on this cap is planed to a mitre on the upper arris of the horizontal leg of the angle, so that the system of cast steel angles by which the outer or up-stream elevation of the cast iron framing is faced, consists of first the sill piece; secondly the two side pieces which converge in order to fit the slight taper on the sluice valve which has already been described; and finally, the lintel or head piece, with its planed and mitred bearings. It was to these planed steel faces that the edges of the strips which make the watertight joints or seals (by which the gate is stanched) were fitted; and when it is considered that in the case of each gate, four bearings, a horizontal bearing at the foot, two inclined bearings at the sides, and a mitred bearing at the head, are required to fit exactly to their respective seats, it will be realized that accuracy of workmanship of an exceptional character was demanded in the construction of the sluices.

The strips and parts of the gate which form hydraulic joints with the planed faces of the system of steel angles, were all constructed of bronze. First, at the foot of the gate a bronze bar 3½ inches by $\frac{9}{16}$-inch was riveted to the lower edge of the steel plate, of which the face of the gate is formed; then a bronze strip

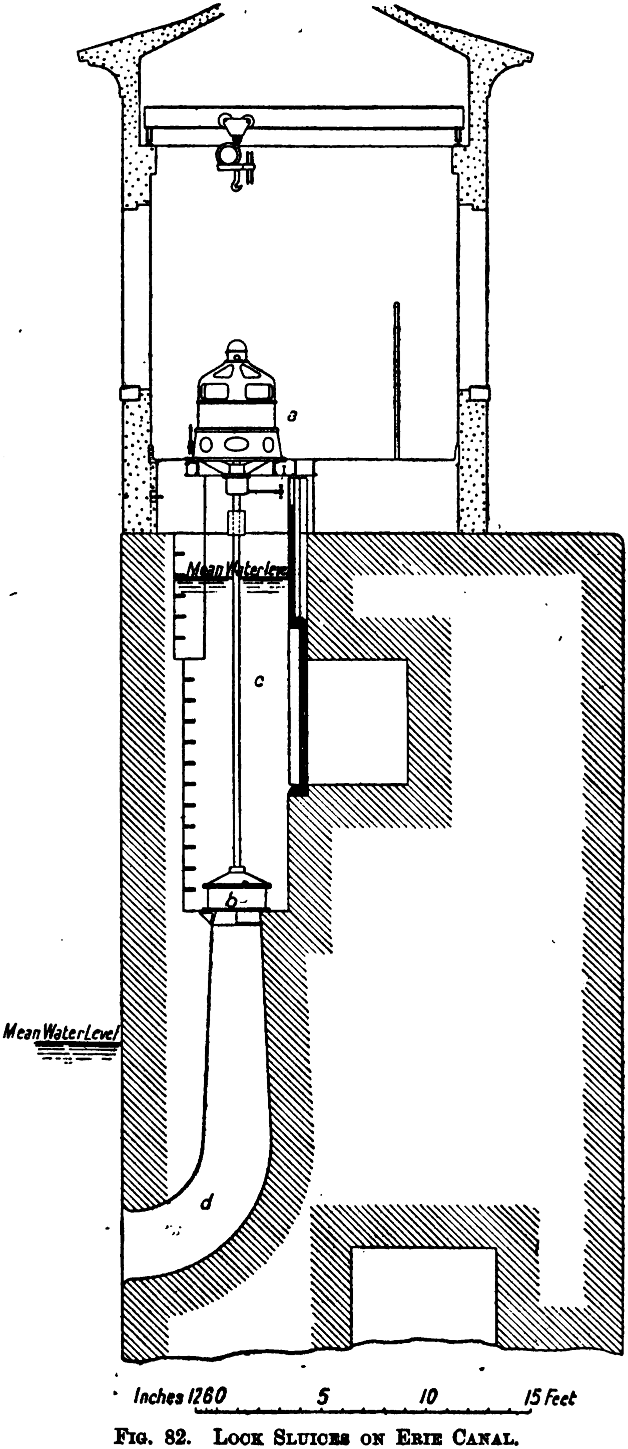

FIG. 82. LOCK SLUICES ON ERIE CANAL.

Electric Generation Plant for operation of sluices.

a Generator. b Turbine. c Shaft to turbine. d Discharge shaft.

5 feet by $\frac{9}{16}$-inch was riveted on each side of the same plate in such manner as to conform exactly with the taper on the cast steel side angles, and finally a bronze bar of which the lower arris is planed to a mitre in such manner as to correspond with the mitre planed on the upper side of the lintel, was riveted to the upper edge of the plate and to the steel angle by which that upper edge is stiffened.

It will be seen that no attempt was made to provide any measure of elasticity in the different bearings, or to furnish any adjustment as between the cast steel system which is attached to the framing in the face of the conduit and the machined edges of the bronze strips which are riveted to the top and the bottom and to the sides of the gates, and that it was not considered necessary to introduce any mechanical device either for the correction of errors in the original work beyond the provision of slotted holes in the bronze strips so as to allow for a certain measure of adjustment, or for the taking up of wear; the extreme accuracy of workmanship to which attention has been called and minute care in adjustment during the construction and erection of each sluice, taken together with the provision of the slight taper at each side of the gate, have been relied upon for the prevention of leakage at each gate and for averting the peril of ultimate destruction through such leakage.

One of the most interesting features in the design of the gates is undoubtedly the system of wheels and axles by which each gate is supported, and on which the gate travels up and down between its girders. For the first part of the lift of the gate the wheels travel on the bearing faces which were cast on each of the steel angle pieces and were attached to the cast iron side posts of the sluice framing. These bearing pieces extend only to a height of 1 foot 4 inches above the top of the gate, or 3 feet $\frac{1}{2}$-inch above the line of the centre of the axle of the upper pair of wheels. From that level and upwards to a higher level (which is some 4 feet below that of the surface of the quay of the lock) extension rails constructed of Z-bars, and which form guides for the wheels (which by the time they reach the extension rails, have been freed from all load), together with the counterweight guides on the other side of the sluice shaft, control the lateral movements in the gate sufficiently to prevent any chattering of the gate in the shaft.

The wheel sluices are balanced by means of counterweights, carried on 1⅛-inch chains and maintained in position by means of guides constructed of Z-bars and of angles secured thereto, and bolted to the opposite or up-stream side of the sluice shaft. The counterweight guides are fixed in position on their side of the shaft in such lines that the play which is left for the wheels in the shaft is only sufficient to obviate the danger of the wheels binding and so jamming between the guides.

The machinery by which the sluices are raised and lowered is of the type which is usually employed when electric motors are used for purposes in which the movement which is ultimately required is simple in character and slow in speed. In the electric machines in question four sets of driving gear are interposed between the shaft of the motor and the shaft on which the chain wheels revolve, and the total reduction affected is in the ratio of 730 to 1 in the case of the 7 by 9 culverts. The chain wheels are of the sprocket, or as such wheels are styled in the North American Continent, the "cupped" type, and their diameter is such that the stroke of the sluices, whether upward or downward as the case may be, and the corresponding stroke of the balance weights in the opposite direction, are truly vertical in line of movement.

One outstanding advantage which has been secured by the introduction of the wheels and axles and by the reduction of the actual load to be lifted against gravity by the employment of counterweights, is that the sluices with their operating machinery have been brought within the limits of hand power for their movement, and can be lifted by manual labour applied through a capstan head by means of levers, and thus can (through a special subsidiary shaft provided for the purpose), in the event of any temporary difficulty arising in connection with the electric supply, operate the reducing gear and so work any one or more of the sluices in any lock.

The large areas drained by the rivers and lakes which feed the Barge Canal system supply a sufficiency of water to permit of the electric current used for the operation of lock machinery being generated at small cost by making use of the superfluous flow and of the differential head at each lock for the purpose. Fig. 82 (to which reference has already been made) shows the direct and effective manner by which a 50-kw. generator is driven by a turbine in Lock No. 7, in which it is situated. But apart from this it is obvious that the consumption of electric current in the working of the locks has been very greatly reduced by the elimination of surface friction due to the introduction of the wheels and axles in the designs of the gates, and through the employment of the counterbalance weights, as described in the foregoing pages.

Altogether the design of the sluice valves on the locks on the new Erie Canal should also command the attention and the careful study of all who are concerned in sluice construction and in sluice working and maintenance; the methods adopted for stanching the leakage at the gates are of more than ordinary interest and are workmanlike and boldly mechanical; the problems which they present are about to be submitted for solution to the most crucial of all tests, the test of continual operation from day to day, and by the result of that test the value of the design will be judged. Most engineers of experience will agree that the most remarkable feature in the whole design is the use of the wheels and axles; particularly when regard is had to the ingenious method by which the complication between the means adopted for reducing the power required for working the sluice gates, and those adopted for preventing leakage past them, which the introduction of either wheels or rollers on the face or down-stream side of the sluices must involve, has been avoided by transferring the wheels and axles to the back or up-stream side of the gate.

In connection with this feature it should be observed that the comparative values of free rollers and of wheels and axles for the elimination of sliding friction in the working of sluice gates deserves much more consideration from sluice designers than have been vouchsafed in the past, and it may now be hoped that the adoption of the wheels and axles in the Barge Canal sluices will force the matter on the attention of designers by whom it has been so curiously neglected.

It may be that wheels and axles have been used for a similar purpose and under similar circumstances before, but no information on the point is at hand; indeed, the only instance of the employment of wheels and axles in sluices of any class of which particulars are available is in the case of a group of flood discharge sluices which were erected at Dutton, on the River Weaver, in the year 1880, which have, therefore, been in continuous use for thirty-five years, and of which it can be said that the cost of their maintenance has been insignificant, and that they have never been the cause of an hour's trouble or a moment's anxiety to those in charge of them since the day when they were completed and set to work.

CHAPTER XI

DUTTON SLUICES ON THE WEAVER NAVIGATION, AND A WORD OF WARNING

One of the sluices referred to at the close of the preceding chapter is shown in Fig. 83, and is described here, as although the Dutton sluices are of the notch type and are employed for the regulation of a canalized river, and are, therefore, not dock or lock sluices of the orifice type, yet some of the special points in their design may be of assistance in working out designs of dock and lock sluices, as there is certainly no reason why the Dutton type of sluice should not be adapted for that purpose.

The group which was constructed consisted of eight sluices in all, divided from each other by stone piers. The openings between the piers were each 15 feet 5 inches in width, and the gates themselves were 16 feet 11 inches in width and 12 feet 11½ inches in height, measured over all. The framing of each sluice consisted of five vertical members, formed of rolled iron joists of *H* pattern and connected together by means of two horizontal beams; these beams were also of wrought iron, and were formed of flanges which were at once built into continuous beams and were secured to the vertical joists, which they crossed by intercostal frames in such a manner as (1) to ensure rigidity of attachment, and (2) to limit the overall thickness of the gates themselves to a width equal to that of the rolled joists plus the thickness of the two flanges of the lower beam and the thickness of the greenheart cleading, by which the back or up-stream side of each gate was covered. The fixed cap at the head of the sluice was formed of pitch-pine timber, as was the tilting cap which, on account of special local circumstances (particularly because of the necessity for the removal of ice in seasons of severe winter), was in each sluice attached to the upper surface of the fixed cap. The foot of the gate was fitted with a cast iron shoe with a bearing toe 1 inch in width, which was planed on the underside in order to fit the sill on which it was to rest. The sill was formed of greenheart timber, dressed to receive and to support the toe of the shoe. At each side of the gate the toe was returned in order to furnish a continuity of seal with a vertical stop which was fitted into the re-entrant angle formed on each side by the combination of a wrought iron strip secured to the back of the gate, and a greenheart bearing piece corresponding thereto, which bearing piece was bolted in the angle of the groove in which each end of the gate was housed. In the re-entrant angle a narrow

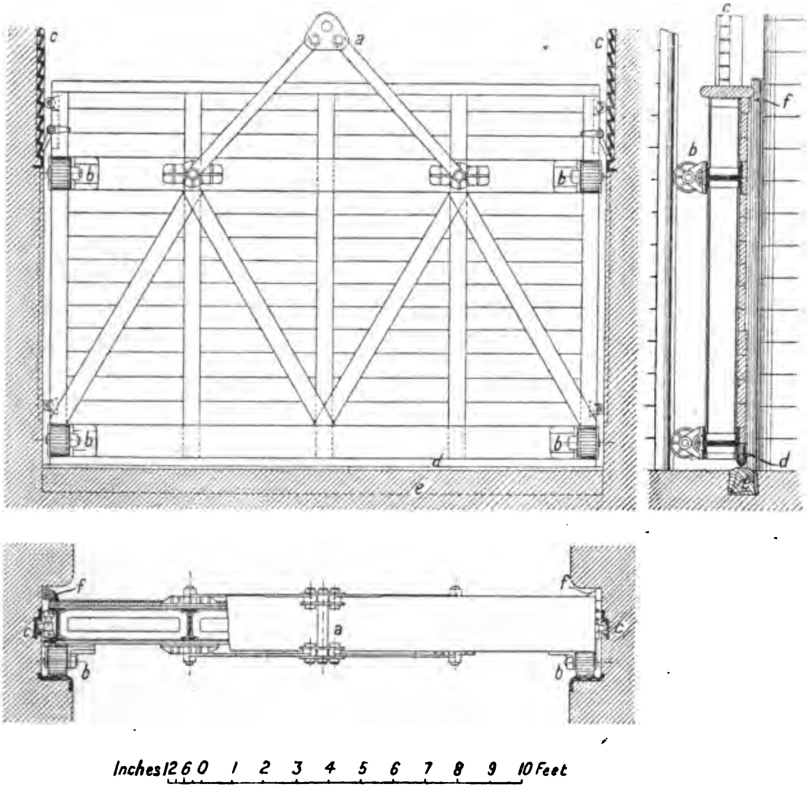

FIG. 83. FLOOD SLUICES ON WEAVER NAVIGATION.

Elevation of face of wheel and axle sluice for regulation of water level.

b b Wheels and axles.
c Supporting rack.
a Connection for lifting gear.
d Cast iron shoe.
e Greenheart sill.
f Greenheart stanching bar.

space was left between the bearing strips, which was closed by means of the greenheart stop referred to, as being fitted into the re-entrant angle at each side, and by means of which the leakage was effectively stanched. The section of the greenheart stop was that of a quadrantal sector of a circle, in which the two straight sides of each stop were dressed to fit the respective bearing faces of the strips on the gates and in the grooves. Each of the greenheart stanching pieces was weighted at the foot to an extent sufficient to make the specific gravity of the whole superior to that of the water, and thus to ensure that the foot of the stanching piece should always rest on the sill and shall bear positively thereon, and yet should leave a *quasi* buoyancy sufficient to permit of the pressure of the water forcing the stanching piece into contact with the bearing strips and thus to prevent leakage. Each closing piece was at its head slung to and lifted by the gate, and unlike the stanching rods in the Stoney type of free roller sluices, the closing pieces have proved effective for the purpose for which they were designed, and are still in constant use after the long test to which they have been subjected.

In the Dutton sluices the face or down-stream side of each gate is supported by four wheels which revolve on independent axles, the bearings for the axles being secured to the extremities of the two horizontal beams already described. These wheels carry the whole of the load due to the pressure of the water on each sluice gate (which pressure amounts under ordinary circumstances to about 33 tons), whether the gate is at rest or whether it is in course of being moved in an upward or downward direction. The wheels are 11½ inches in diameter by 7 inches in width on the face, they are bushed with gunmetal, and the axles on which they revolve are 3⅜ inches in diameter. The sluices are not counterbalanced in any way, nor was any power provided for their operation, as each sluice is easily moved under full head by the muscular force of two men applied through a crab or winch which traverses backwards and forwards on an overhead railway, by which crab the sluices are raised or lowered in succession. When the sluice gates are lifted in order to permit of the passage of flood waters, the gates are supported at each end by the rack and pawl arrangement which is shown on Fig. 83.

The experience which has been gained in the operation of Dutton sluices has been distinctly encouraging so far as the use of wheels and axles for the purpose of eliminating sliding friction is concerned, and there seems to be no reason why wheels and axles should not be embodied in designs for the sluices in locks and in dock entrances, whether they be fixed on the face of the gate, as at Dutton, or applied in the ingenious manner adopted in the sluices for the Erie Canal system.

In comparing the two types of rolling sluices, that is to say, the free roller type with that in which wheels and axles are employed, it may readily be admitted that theoretically the free rollers have the advantage. The load per linear inch is reduced by the great number of rollers employed. The travel of each roller is only half that of the travel of the gate itself, and the system is undoubtedly mechanically correct, so that if the question of leakage be ignored, the results obtained therefrom are admirable so long as the rollers and the roller paths remain in perfect condition; but when the rollers wear, and wear unequally, and the paths upon which they move up and down also wear in the same unequal way, the balance is disturbed and the mechanical advantages are lost to a great extent if not altogether; when, therefore, the length of the serviceable life of the wheels and axles, and the moderate character of their charges for maintenance, are brought into the comparison, extended experience of the working of both has led to the very decided conclusion that the case for the wheels and axles is, to say the least of it, nearly, if not quite, as strong as that for the free rollers when the element of loss of water through leakage is not a serious factor in the comparison of merits and demerits. Where that element is predominant the advantage inclines to the side of the simpler system, i.e. to the side of the wheel and axle type.

Before passing on from the consideration of the details of so important and so difficult a branch of the subject of dock and lock machinery as that which relates to the construction and operation of sluices for the regulation of the levels in maritime gateways, and proceeding to the discussion of cognate branches of the same subject, a further word of warning (drawn from actual experience) to sluice designers may be adventured. The necessity for the warning arises from the fact that seldom, if ever, does it happen in practice that the man who is responsible for the design of the sluices becomes subsequently responsible for their working and for their maintenance. In most cases the sluices are supplied and erected by contractors, under the provisions of a contract which imposes upon the contractors a liability for the maintenance of their work for periods of three months, six months, or twelve months as the case may be. The ordinary provisions for maintenance in the specification of an engineer who knows his work are of high value, as they are sufficient to compel any contractor or firm of contractors, to make good at his or their own cost all defects in materials or workmanship which may arise or develop during the period of maintenance. In some specifications attempts are made to lay upon the contractor the responsibility for and the liability to make good defects due to design. These attempts are just and equitable in cases in which the designs were prepared by the contractor, and the work was carried out according to the contractor's ideas and to the contractor's drawings. But in cases in which, as is usual, the designs were supplied by the engineer and were carried out with scrupulous accuracy by the contractor, the desire to make one man responsible for another man's errors seems to indicate that the sense of equity has become a little blurred, and that the conception of abstract justice has grown hazy; but even in such cases, and when the contractor is willing to assume and to bear the burden of responsibility for a period of maintenance of six or even twelve months in respect of works such as those involved in sluice formation, that period is but a small proportion of the period (which may be twenty-five years or may be fifty years, according to the number of times per annum at which movement of the sluices is required), during which the sluice gate and its operating machinery should remain in useful existence.

Experientia docet is an ancient Latin tag which engineers of the present day, who are too busy to trouble their heads with classic lore, usually render "experience does it" (a translation which, after all, is not far from the spirit of the meaning of the venerable dictum), and experience has taught many men who have had to work and to maintain sluices which have to be raised and lowered many times a day, that one of the very first elements in every design for a deeply submerged sluice which is to be built for the control or regulation of waters, should be feasibility of examination at all times, and of repair or renewal when these are required. Possibilities of examination and repair by divers being discarded (as a diver can do little or nothing amidst the cramped conditions of a sluice shaft), two methods of meeting the need, and two methods only, seem to be available. The first method is that which was adopted in the design of the locks on the Panama Canal, and consists of removing the water from the sluice, which means closing the connections between the lock or entrance and the water in the particular part of the conduit where the sluice is situated, and pumping the water out of the sluice shaft and away from the sluice itself; while the second consists of constructing the sluice, the sill, and the lower parts of the grooves in which the sluice rises and falls, in such manner that the whole can be raised as an entity, bodily out of the water. In either case the arrangement of the details will be sufficiently difficult to goad the designer into taking pains with his work, and should provoke his prescience into an endeavour to contemplate seriously the appearance which his design will present, not on paper—where too frequently his connection with the design begins and ends—not even when his sluice has been erected and completed in the place which it is to occupy in the works before the admission of the water, but after the sluice has been in place, and has been operated, has been raised and lowered and subjected to the destructive force of rushing waters some thousands of times per annum, for any number of years which the designer chooses to determine as the life of his design.

This is the word of warning which is ventured here as an outcome of the experience of one who looks back on a long vista of by-gone years; and one suggestion is that the designers of works in subaqueous situations, of which any parts are to be regarded as movable and are proposed to be secured by means of screwed bolts and nuts, should make themselves practically acquainted with the condition which these fastenings will be found to present after they have been subjected to the corrosive action of salt or polluted waters, for any lengthened period.

CHAPTER XII

THE NEW ERIE CANAL AGAIN: AN ADVENTUROUS ENTERPRISE AT OSWEGO: A SYPHON LOCK

THE "hundred and one million dollar canal" system* comprises one main canal which extends from Waterford, which is on the Hudson River and lies about 14 miles above Albany, the administrative capital of the State of New York, to Tonawanda, which is situated on a branch of the Niagara River (on which river the navigation is carried on to Buffalo, the entrepôt for American trade on the Great Lakes, and to Lake Erie), and six branch canals of varying lengths and importance connected therewith, namely—the numbering is from west to east—(1) A short branch on the northerly side of the waterway which extends to the City of Rochester, a well-known centre of boot manufacture; (2) and (3) two short branches on the southerly side, of which (2) connects the waterway, through the Cayuga and Seneca Canal, with the Seneca Lake, and (3) forms the connection with the Cayuga Lake. (4) Another short branch on the southerly side which reaches the City of Syracuse; (5) a longer and more important branch from Three Rivers to Oswego, on the northerly side of the Canal, but on the southern shore of Lake Ontario; and (6) the longest and most extensive branch of all, which commences at the junction of the main canal with the Hudson River, at Waterford, and extends to

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* Mr. Frank M. Williams, who resumed the functions of State Engineer and Surveyor to the State of New York at the beginning of 1915 (in succession to Mr. J. A. Bensel who had succeeded him in 1911) and who is now, therefore, in charge of and is responsible for the completion of the Barge Canal Works; has estimated that the cost of the canal will exceed the amount of $101,000,000 appropriated therefor, by the sum of $27,000,000. Mr. Williams has explained in detail the sufficient reasons to which the increase has been due, but it is not necessary for the purposes of this manual that we should enter into any consideration of these reasons here.

Lake Champlain. On the main line of the waterway and on the branches thereof there are altogether between sixty and seventy locks, the falls at which vary from 40·5 feet to 6 feet. With one marked exception the levels of the water in this multitude of locks are regulated and controlled by sluices of the type which has already been described in detail and illustrated in these pages.

The exception is the lock at Oswego, through which the junction between the Oswego branch and the waters of Lake Ontario is effected, and which furnishes a notable and a most interesting variation from the general run of the locks in the Barge Canal system. In that system Oswego will be not only a junction, but a terminal, and one of such a character that no less an authority than Mr. John A. Bensel (late State Engineer of New York) has expressed the opinion that " Oswego will be one of the most important, if not *the* most important terminal along the line of the new waterways." At the Oswego lock the fall varies from 11 feet to 8 feet, and the method by which the levels are regulated in that maritime gateway differ so essentially from that employed in the other locks on the system, that British engineers, without loss of the dignity which becomes them so well, and which they prize so highly, may well acknowledge their indebtedness to the State of New York as a whole, and more particularly to the American engineers responsible for the design and construction of the Barge Canal system, for adventuring so far as to construct as a part of that system the syphon lock at the point where the Oswego branch joins Lake Ontario.

The Oswego lock, which was completed and brought into operation in 1910, was the first syphon lock constructed on the western coast of the Atlantic, and although it has precursors on the Continent of Europe, no lock like unto it has yet been built in the United Kingdom. It is not claimed that the syphon lock at Oswego is of original type or design ; on the contrary, the engineers of the Barge Canal have stated plainly that the " first syphon lock was completed about 1896 on a canal in Northern Germany, and was designed by Professor Hotopp, of Hanover." This original syphon lock was constructed on the Elbe-Trave Canal (which crosses the Holstein Peninsula) in a more or less experimental way ; the experiment was successful, as the operation of the lock proved to be simple in character and effective in result; and the outcome was that six additional locks on the same canal were constructed of a similar type. Following the experience thus gained, further syphon locks were built at various parts in the northerly provinces of the German Empire since that time. Under the circumstances which exist at the time of writing, up-to-date information as to the working of these syphon locks cannot be obtained, and the particulars relating to the larger and more modern Oswego lock are offered in lieu of any record of the German structures.*

Figs. 84 to 90 (inclusive) show generally the methods adopted in the designs for the syphon lock at Oswego and the arrangements of the conduits in that lock. The most remarkable of the illustrations is certainly that in the part of Fig. 84, in which one side of the lock is shown in sectional plan, as the conduit by which the regulating waters are permitted to flow from the upper to the lower portions of the lock, appears in that Fig. 84 to be without stop or break of any kind since the lines of the conduit have been drawn without interruption from the upper to the lower end of the lock. It must not be concluded from this sectional plan that omission has been made in the diagram or that inaccuracy has occurred in the drawing. An examination of the longitudinal section, in which the syphonic method of the construction of the conduit is clearly shown, will explain what appears to be a mystery. If the section be studied in detail it will be observed that a tank is shown thereon in a position which is a little below the upper leg of the syphon. A corresponding tank was built on the other side of the lock so that there are two tanks in the lock in all. Each of these tanks has a length of 21 feet, a width of 7 feet 6 inches, and a height of 7 feet 9 inches, or a total capacity of 1220 cubic feet in each tank. The tanks are divided into two by means of central transverse partitions, and are cut off entirely from communication with the atmosphere, except through pipes with which they are fitted, and through manholes with airtight covers which were

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* In 1906 the engineers in charge of the German syphon locks spoke favourably of their experience with them; the only objection which they took to the syphon system being due to the fact that in the case of an accident to a boat in a lock the flow could not be stopped as quickly as if the lock were equipped with culverts controlled by valves; but the difference between the two can only amount to a few seconds at the most, and can, therefore, not be regarded as of sensible importance.

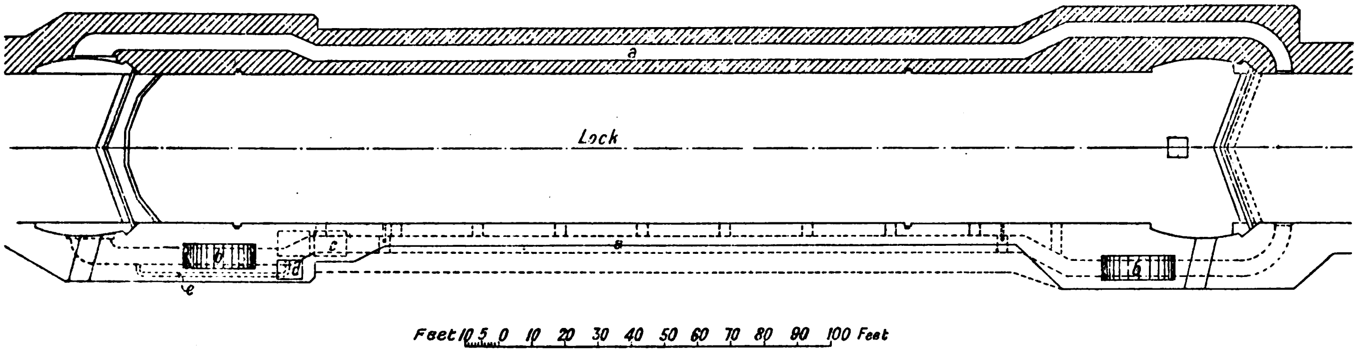


Fig. 84. Syphon Lock at Oswego, Erie Canal.

General plan of lock.

a a Conduits. *b b* Crests of syphons. *c* Vacuum tank.
d Valve chamber. *e* 12-inch filling pipe.

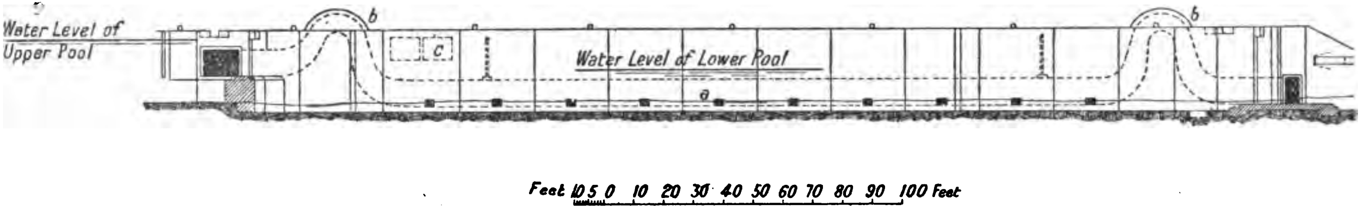

Water Level of Upper Pool
b
c
Water Level of Lower Pool
a
b
Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

Fig. 85. Syphon Lock at Oswego, Erie Canal.

Sectional elevation of side of lock.

a Conduit. *b* Crest of syphon. *c* Vacuum tank.

constructed in the syphons. The tanks are in the first instance filled by means of longitudinal pipes which are 12 inches in internal diameter, and are used for the purpose of filling the tanks with water, which is derived from the level of the pond of the above lock. The water from the tanks is discharged, and in this way each tank is emptied by means of vertical pipes which are 20 inches in diameter and through which communication is effected between the tanks and the level of the water in the Oswego River on the westerly side of which the lock was built. On each side of the lock the upper and lower syphons are connected with the tank on their own side by means of two separate lengths of 4-inch pipes, the connection with the pipe from the upper syphon being formed at the upper end, and that from the lower syphon at the lower end of the tank in each case.

The lock is worked, or in other words the water therein is regulated, by means of these 4-inch pipes. It should be observed *en passant* that the cubic contents of a single tank are nearly double the contents of one of the syphons, measured from the level of low water. If, therefore, the dimensions of the tanks err at all they err on the side of generosity; a side to which the engineering professsion might well be directed in somewhat larger measure, whether from an ethical or mechanical point of view.

The methods by which the levels in the locks are regulated are as follows: Each of the 20-inch emptying pipes is closed, and each of the 12-inch pipes for filling the tanks is opened, with the result that water from the upper level rushes violently into the tanks, from which the air blocked up in the tanks is driven through the valves marked *B*, and the valves marked *A* (Fig. 87), which are used for starting the flow, are also opened. During the operation of filling the tanks the neck of each syphon is maintained in temporary communication with the atmosphere, but "as there is no drawing tendency of the air," no change takes place in the level of the water in the syphon. The air escapes through the 4-inch pipes with considerable force, so that the tanks are filled in about four minutes from the time of the opening of the 12-inch pipes. These valves and the controlling valves marked *A* and *B* are then closed, and the corresponding valves *A* and *B* at the lower end of the lock are also closed, communication being thus cut off between the tanks and the syphons above and below the tanks. The outlet

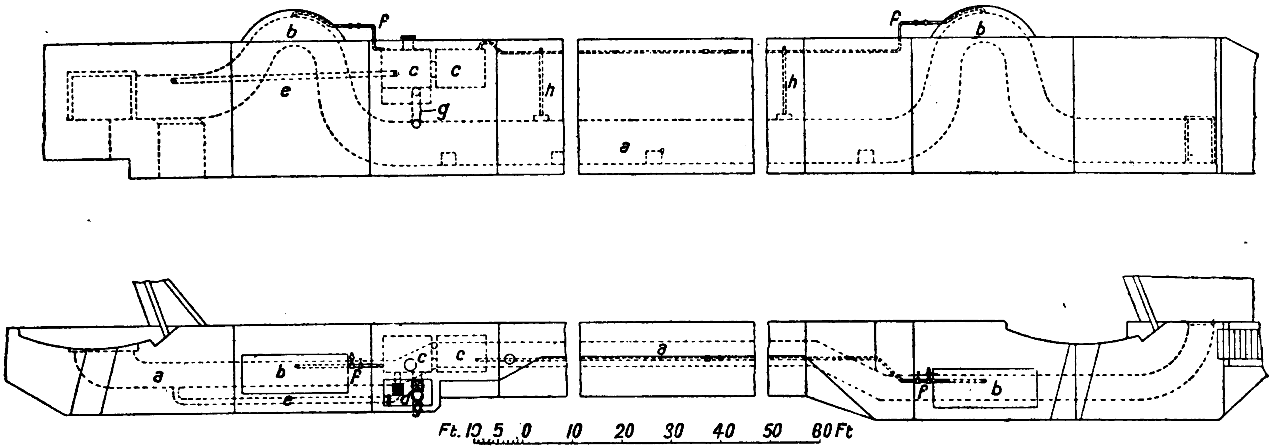


FIG. 86. SYPHON LOCK AT OSWEGO, ERIE CANAL.

Enlargement of syphons in side walls of lock.

a Conduits.
b Crest of syphon.
c Vacuum tank.
d Valve chamber.
e 12-inch filling pipe.
f f 4-inch air pipe.
g g 20-inch outlet pipe.
h h 6-inch air vent pipe.

valves on the 20-inch vertical pipes are then opened, and the effect produced in each tank is that of a body of water which is in a state of suspension, but which tends to escape under the action of gravity into the adjacent river until equilibrium between the downward hydraulic pressure, and the upward atmospheric pressure, is attained. Under that condition the tank is shut off from all communication with the outer air, and the water remains suspended in a condition of balance and produces the vacuum necessary for the operation of the lock. A vacuum gauge is placed at each syphon, so that the man in charge may ascertain how much power is available for the operation which is required. During the filling of the tank the needle of the gauge stands at zero, but as soon as the filling is completed and the opening of the 20-inch valve begun, the needle begins to move slowly upwards, and finally stops at the point which corresponds with the difference in head between the upper and lower levels. This, as is usual in the case of vacuum gauges, is indicated in inches, and corresponds with the difference in height which would be produced in a column of mercury by the differential head between the two levels of the water. Thus a differential head of 8 or 9 feet which, having regard to the variations in the level of Lake Ontario, may be regarded as the average of the conditions under which the lock is worked, is indicated by a reading of from 7 to 8 inches on the dials. The pressure per square inch as compared with the pressures employed in steam or internal-combustion engines is very small, as a head of 8 feet would not produce a greater pressure than 3½ lb. per square inch. On the other hand, the area of the water surface in each tank is 157·5 feet, so that the pressure in the tank is equal to a weight of over 35 tons. When the filling of each tank has been completed and the outlet valve on the vertical pipe has been opened, the flow of water may be started. If it be desired to fill the lock, all the valves being closed, as already indicated, valve *A* at the upper end must be opened, when the air in the syphon will rush into the vacuum which has been produced in the tank, will displace part of the water in the latter, and will permit it to escape through the 20-inch outlet; the water will then rise in the syphon until it reaches its crest, and will begin to flow over that crest into the conduit below. The tank will continue to draw out the air, and as soon as the water in the syphon has risen to about one-third of the height between the crest and the

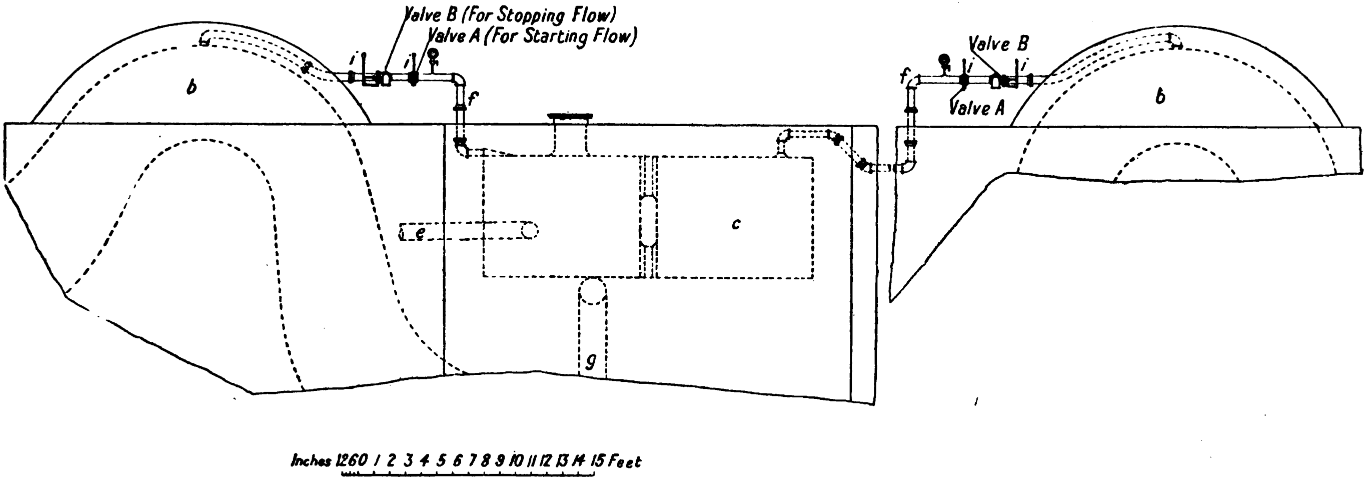

Valve B (For Stopping Flow)
Valve A (For Starting Flow)
Valve B
Valve A
b
b
c
e
f
f
g
i
i
i
i
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

FIG. 87. SYPHON LOCK AT OSWEGO, ERIE CANAL.

Details of syphons in side walls of lock.

b Crest of syphons.
c Vacuum tank.
e 12-inch filling pipe
f 4-inch air pipes.
g 20-inch outlet pipe.
i Operating levers.

crown (equal in this instance to nearly 2 feet), a part of the air will begin to pass out through the culvert. Under the principles of natural law, to which the operations of syphons of this type are due, when the water has risen to the height named it will begin to drive out the remainder of the air, and the syphon will thereafter fill itself automatically, provided the bubbles of air can find an escape through an efficient outlet.

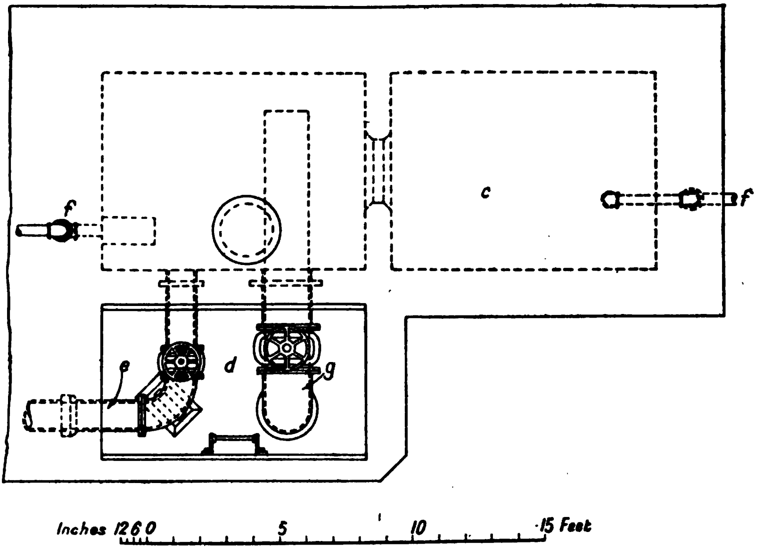


FIG. 88. SYPHON LOCK AT OSWEGO, ERIE CANAL.

Enlarged plan of vacuum chambers for syphons.

c Vacuum tank. *d* Valve chamber. *e* 12-inch filling pipe.
f f 4-inch air pipes. *g* 20-inch outlet pipe.

The action thus described takes place in much less time than has been required for its description here; as a matter of fact, with a differential head of 8 feet the syphon begins to prime itself in a period of from 30 to 40 seconds. At this period the needle of the gauge, which recedes several inches as soon as the valve *A* is opened, begins to rise again, and the syphon at the same time reverses the action of the tank, so that instead of air being drawn into the tank, the syphon begins to draw back air from the tank and to carry it out into the culvert. A certain amount of water from the river flows up into the tank at the same time through the 20-inch outlet pipe and supplies the place of the air, so that in a few minutes after valve *A* has been opened, the original vacuum is restored in the tank. The movement still continues, however, and continues until the tank and the pipes have all been filled with water, at which time the needle of the gauge usually registers 3 or 4 inches more of vacuum than at the time of starting.

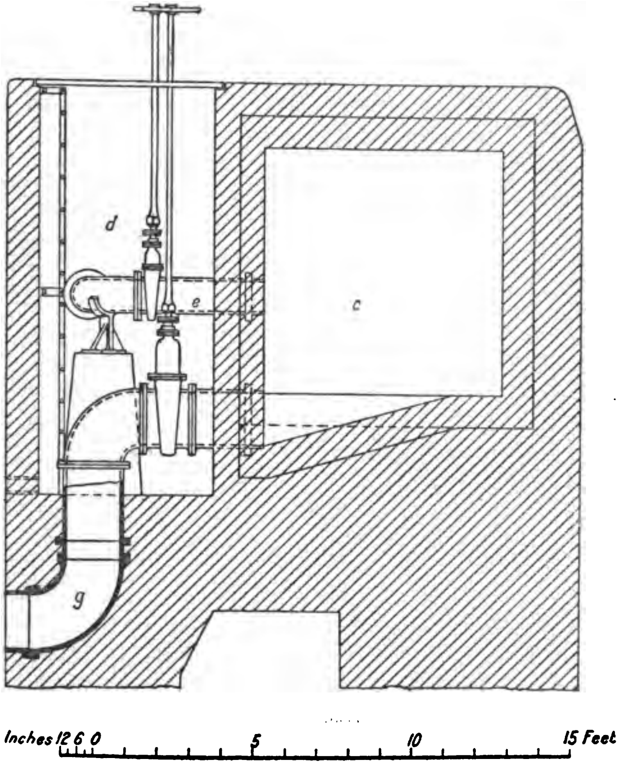


FIG. 89. SYPHON LOCK AT OSWEGO, ERIE CANAL.

Enlarged section of vacuum chamber for syphons.

c Vacuum tank.
d Valve chamber.
e 12-inch filling pipe.
g 20-inch outlet pipe.

A series of experiments were made with a float gauge in the tank in order to ascertain the degree of rise and fall which takes place in the water, and it was found that when the reversing action began, the operating head of water in the tank was nearly 2 feet in excess of the head in the syphon. It might have been expected, therefore, that the tank would have continued to draw air out of the syphon until this head was neutralized, but in point of fact the draught of the syphon was so strong that it not only overcame this difference, but commenced at once to draw up the water into the tank, filling it again completely.

The air which is carried out with the water escapes for the greater part through the air vents in the walls, which are shown on the illustrations, but also escapes to some extent, in small bubbles, through the openings to the conduits. At the air vents there are, in the first instance, discharges of mingled air and water which are thrown outward to a distance of a few feet on the side of the lock wall, but as the volume of the flow through the syphon increases the jets also increase in volume, until at times the discharge becomes a cloud of spray extending over a distance of 50 to 60 feet. In the event of this discharge causing inconvenience to boats or to boatmen at any future time, it is intended to remedy it by placing baffle plates at the openings in order to intercept the spray. Practically the whole of the discharge of air takes place through the up-stream vents and conduit openings, and only a small portion of air ever reaches the down-stream vents.

With both syphons in use, the lock chamber, which is 338 feet 6 inches in length, and 45 feet in width, and in which the differential head varies from 8 feet to 11 feet, can be filled in from 4½ to 5 minutes. As the level of the rising water reaches that in the upper reaches of the canal, a surge (which is not infrequent in cases in which the conduit and lock chamber are of such large dimensions) takes place. The surge is due to the fact that owing to the momentum in the inflowing water the water continues to flow for a few seconds after the level in the lock chamber has reached that in the canal outside, so that the level in the lock rises slightly above that in the adjoining reach of the canal, and thus commences to open the gates at the upper end of the lock.

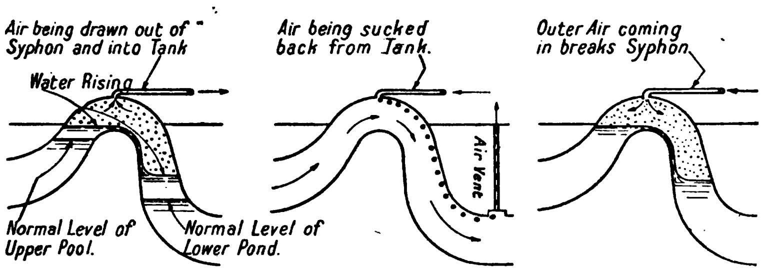
For the discharge of water from the lock: before the lower syphon is started valve *A* is closed and valve *B* which admits the air to the upper syphon, is opened, thus permitting the water in the neck of the syphon to fall below the level of the crest. Unless this operation be performed any difference of level in the lock chamber which might exist and due to the commencing to discharge would set the water in the neck of the upper syphon running again, in which case it would be impossible to empty the lock chamber without stopping the flow.

Having regard to this necessity the lowering of the level of the water in the lock chamber by the discharge of the water therein, is accomplished by a process similar to that employed for the raising of the level. If the valve *B* at the lower syphon had not been left open during the filling of the lock chamber, so that the air in the syphon could find an escape as the water rose, it must be opened for a few seconds and then closed again before the discharge of the water from the lock is begun, as otherwise there would be an excess of air inside which would go far to neutralize the value of the vacuum in the tank. It has been observed that the lower syphons act less rapidly than the upper syphons, as the air has to travel to the tank through a longer distance, i.e. through a length of about 250 feet of pipes in each wall, and has to pass around several bends. Moreover, the air which the water begins to carry out after the syphon has commenced its self-priming operation, does not escape as readily as at the upper end, as it has a less direct route to travel on its way to freedom. The experiments which have been made have shown that the operation of lowering the level takes from 45 seconds to a minute longer than that of raising the level, the first discharge of air appearing when lowering is taking place, at the conduit opening in from 1½ to 1¾ minutes, although the vacuum gauge indicates that the flow of air from the syphon to the tank reverses in about 45 seconds. As the outflow increases, the amount of air carried in the water continues to increase so that for a minute or two the discharge consists of a mass of aerated water, formed of a compound of air bubbles and fluid, which gradually changes in composition until all the air has been discharged and the flow consists of water only. The vacuum gauge, as in the case of that for the upper syphon, registers a steadily increasing vacuum until the point is reached when the discharge is in full play, and the value shown on the gauge becomes as high as 13 or 14 inches, or nearly double that shown at the commencement of the operation. After the flow has stopped the needle gradually settles back to the original figure referred to. The discharge of the water from the lock when both syphons are used takes from 5½ to 6 minutes.

It will appear from the foregoing description that once the tanks have been made ready for work the operating power is of a self-recuperative character; if, therefore, no leakage of air took place into the tanks, lockages could be conducted at any time merely by the manipulation of the 4-inch air valves. Under these circumstances an approach, as near as is mechanically possible, would be made to a state of perpetual motion, as the syphon lock would become an integral part of the great cycle in which the heat rays of the sun not only lift waters from the lakes and the seas, in the form of inpalpable units, but lift them to an elevation sufficient to condense the units into clouds which intercept and interrupt their parental rays in such manner that the lower strata of the clouds are further condensed to such an extent that they are precipitated upon the earth in the form of rain, in which form and under the influence of gravity they pursue their way into the brooks, the streams, and the rivers, and so find an ultimate resting-place for the time being in the seas from whence they derived their origin, in which resting-place they are again brought under the influence of the heat rays and are once more started on their circuitous course.

But the harmony of this fragment of the motion of the spheres is marred by the fact that leakage is inevitable in a leaky world, and that the conduit system in the syphon lock at Oswego is not exempt from the conditions of its environment. In that system leakage does take place to a sensible extent, but notwithstanding this fact the tests which have been applied and the experience which has been acquired in the working of the lock, have indicated that each tank will retain a sufficient vacuum for two or three hours after the last lockage. As a result of this experience, in ordinary working and for the purpose of avoiding the refilling of the tank when traffic is infrequent, the method has been adopted of closing the 20-inch outlet valve from each tank, thus holding the water in place in the tanks. On opening the valve again the apparatus becomes at once ready for use.

The working of the syphon lock at Oswego began on the 28th May, 1910, and it is not too much to say that the result of the experiment has been entirely satisfactory from the outset. To a large extent the intricate problems which must be confronted in the design and construction of ordinary lock sluices have been solved, and the almost insuperable difficulties connected with the maintenance of such sluices and their protection against leakage have been eliminated by the simple process of abolishing the sluices themselves, and as a matter of fact the movements of the water into and out of the lock at Oswego are controlled by the two 4-inch valves which are fixed at each end of the two walls of the lock.


Air being drawn out of Syphon and into Tank
Water Rising
Normal Level of Upper Pool.
Normal Level of Lower Pond.
Air being sucked back from Tank.
Air Vent
Outer Air coming in breaks Syphon

Starting Syphon   Syphon flowing Full.   Syphon being Stopped

FIG. 90. SYPHON LOCK AT OSWEGO, ERIE CANAL.

Diagram showing connections for working of syphons.

The contrast is so great between the working conditions at Oswego and those which obtain at other locks on the new Erie Canal and on its branches, that outsiders may be forgiven if they ask why it is that, seeing that out of the sixty or seventy locks which form part of the great system of inland waterways, many of which have falls which come within the limits of the varying fall at Oswego, the adventure so gallantly undertaken was not carried further; or, in other words, why a greater number of these locks were not built of the syphon type. None the less the enterprise was one which required some courage, and engineers of other lands, who have ignored syphon locks altogether, may well congratulate the engineers of the Barge Canal on the success at Oswego which has crowned their boldness; and may further thank them for having shown the way in what will undoubtedly prove to be an advance on lock construction, an advance which will in the cases in which the syphonic system is applicable have an important bearing on the questions relating to sluiceways, sluice gates, and sluice valves, which have been discussed in this monograph.

CHAPTER XIII

MOVING AND BERTHING IN, AND REMOVING SHIPS FROM, MARITIME GATEWAYS

OF the questions which have emerged during the amazing process of growth and development which has led to the production of the leviathans of the ocean routes which present so marked a feature in twentieth-century life, and concurrently with that production, of the construction of gateways of the seas and navigable rivers suitable thereto (or, in other words, of great ships, and of entrances and locks which are capable of accommodating them), none have received so little attention or have occasioned so little comment as those which relate to the manipulation of moving vessels in and through the entrances and the locks. Even engineers seem in some cases to have failed to realize in their own minds the measure of the capacity for destruction which lurks behind the innocent appearance of a vast, heavy, but slowly moving ship, or to appreciate fully the kinetic force which is stored up in that calm, creeping leviathan, or the contrary force which must be exerted—perhaps in a sudden emergency—in order to take the way off the vessel in a manner which is sufficiently near to instantaneous to prevent accident in such an emergency.

The case is essentially one of personal apprehension, one in which each man must grasp his own nettle, as little help can be obtained from outsiders or from the recorded experience of others. Seafaring men—in which generic term, pilots, dockgatemen, lock keepers, and the like are included here for the sake of simplicity—whose experience in the actual handling of vessels is naturally much greater than that of engineers, are a stiff-necked generation, and individually are occasionally persons who are temperamentally obstinate; consequently very little assistance can be obtained from them so far as what may be described as the engineering side of the questions referred to is concerned, and even less with regard to the dynamical problems which are involved in these questions. Further, those who have had to deal with these mariners know that if any question of serious import be submitted to them, men of every degree who go down to the sea in ships disagree among themselves in a manner more pronounced than even the doctors, whose differences have become proverbial, and, moreover, are unable to conceal their disagreements with the skill for which in this particular the members of the medical faculty have won such just renown. Had the case been altogether different, and had really valuable aid from without been obtainable for the asking, it is doubtful whether the designer would have been much better off than he is under present circumstances; as the first element in the design and provision of machinery by means of which vessels of varying sizes and weights can be handled with safety and assurance, should obviously be the possession of information derived from personal observation such as can only be obtained by patient and critical study made on the spot itself, the spot being in this case the quay of a lock or entrance into and out of which heavy vessels are continually being moved.

There is another element which is generally overlooked and to which, therefore, reference should be made in a manual such as this; but the matter is a delicate one, and one in which it is above all things desirable that reference, even of the most guarded character, to places or to persons connected with such incidents as those which must be alluded to should be avoided. In an initial way it will be sufficient to say that there is a particular class of perils which not only exist, but which are very frequently present when floating weights are being moved, to which little or no recognition has been extended, but which unquestionably do from time to time affect the working of dock and lock machinery.

The class of perils referred to are those which are inseparable from the working of so fallible an entity as the human machine. In the conduct of the business carried on by the units of the earth, whether these be imperial units, or national units, or small local units, down to the last possible unit, the individual man, practically everything depends upon trained human intelligence operating through the complex system of nerves, muscles, etc., by which the physical part of the human unit is controlled. Given instructed minds and skilled hands, in the vast majority of cases the work entrusted to these minds and hands will go on with automatic regularity and with perfect accuracy until success is attained and the desired object is accomplished. This is the general rule, but it is far from being a universal rule from which there is no exception.

For the present purpose, and as an example of what is meant, the case of a man in the engine room of a steamship may be taken as being in point. The position is a difficult one. An engineer in charge of the engines in such a room is shut in from the world which is without, sees and knows nothing of what is going on, and is, moreover, shut in to heavy and unfavourable conditions of atmosphere, and to the distracting clamour of rapidly moving engines. Amidst these unfavourable circumstances the man in his place of solitariness has no guidance or direction except such as he receives from the movements, sometimes the very frequent and jerky movements, of the finger on the dial of the telegraph through which he receives his orders from the bridge : " Half speed ahead," " full speed ahead," " stop," " half speed astern," " full speed astern," and the like, and in accordance with which he drives and controls his engines. Can there be any cause for surprise if a man in such surroundings who has with accurate intelligence responded to such orders correctly on ten thousand different occasions, should go wrong on the ten thousand and first occasion ? and when the orders to go " half speed astern " has been given to him, should unwittingly put his engines " half speed ahead."

Whether or not the question causes surprise to persons who are unfamiliar with cases such as that suggested, and who are oblivious of the fact that they make similar mistakes themselves daily, the fact remains that the occurrence is one which is by no means infrequent, and that in some cases mistakes are made, sometimes, indeed, on the bridge, from which wrong orders may be given by mistake, and in other cases right orders are given and incorrectly and in sheer mistake are wrongfully read and acted upon, are acted upon twice in succession, and on some occasions have been made even when two observers are engaged in the same part of the same engine room.

Whether such an error as that indicated has had its origin on the navigating bridge above, or in the engine room below, it is easy enough for the least skilled person to understand how lamentable the consequences of the error may be should it occur in a dock entrance or in a lock, when the gates are closed against the ship, when a considerable head of water exists behind the gates and is upheld by them, when the vessel is thought to have too much way on her, when effort is made to take the way off by putting the engines astern, and when through the error the movements of the ship are accelerated because the engines are speeded up ahead. Occurrences of this kind and the consequences attendant upon them are almost invariably reported in the Press, they cannot be hid, and as a matter of fact, there are few places on the salt seas or on the fresh waters which have not their own tale to tell of disaster which has overtaken ships or structures through the sequence of facts which we have sketched so slightly. A steamer entering an entrance of a lock or approaching a quay or a wharf with too much way on her, is observed by the navigator in charge, captain or pilot as the case may be, to be in peril, with the result that the man in control attempts to use the vessel's own engines in order to reduce the speed, and therefore telegraphs, or intends to telegraph, to the engine room the order to go astern—that is to say, to reverse the direction in which the propeller is revolving—and either unconsciously makes a mistake in transmitting the order to the engine room, or has his order misinterpreted by the man at the engines. The resulting consequence is that the propeller or propellers which ought to have been used for reducing the speed of the ship have inadvertently been used for increasing that speed, and that to such an extent that collision occurs and not only are the bows of the steamer crushed and her stem post broken, but every obstacle to the vessel's mad career, whether gates in entrances or in locks, or walls or frames in quays and wharves, are one by one not only doomed to destruction, but effectively destroyed. The direct consequences of such an occurrence are serious enough, but even they frequently sink into insignificance when compared with the indirect consequences due to the sudden discharge of great masses of water moving at high velocity, or to the stranding and on some occasions the sinking of large steamers, which have been affected either in one way or another by the unexpected outflow. In every case in which such error has been made and such damage has followed, the immediate cause of the damage was the error which was due to that which we have ventured to describe as the fallibility of the human machine; but the root of the matter lay in the fact that those in charge of the vessel were permitted to employ the ship's engines and the ship's crews to control, or attempt to control the speed of the vessel when she was in dangerous proximity to possible obstructions to her course.

If all dockowners and engineers are not alive to the perils which encompass the course of a vessel while making her way to quays and wharves and through entrances and locks, the shipowning fraternity, who are amongst the keenest of the keen business men of these modern times, have not only been fully alive to these perils, but in their wideawake way took steps long ago to divert a sensible proportion of the burden of the responsibility for the cost of the repair of any damage which might be occasioned to permanent structures by their ships, from themselves to the proprietors of these structures. The *modus operandi* adopted by the shipowners and by the powerful clubs through which shipowners supplement the insurance work of their underwriters, will be referred to later on; in the meantime it is sufficient to say that the change which was brought about by their efforts was so serious as to render it inevitable that methods should be adopted by which protection might be afforded to owners of docks and waterways against the risk of loss due to the increased responsibility which has been laid upon them by the action of their shipowning friends.

It is obvious that the most complete form of protection could have been found in prohibiting a steamer from moving her engines at all when in or near a permanent structure of the class described. But as movement is the *raison d'être* of a steamship and of her engines, and as in the particular case which is the subject of discussion, it is in the first place essential to get the ship to the quay or wharf or into the entrance or lock, and in the second to get her away from it as quickly as is practicable consistent with safety, it is equally obvious that if the ship's engines are not to be used for the propulsion of the vessel either ahead or astern, a substituted method of movement must be provided.

A simple and reasonably safe method of moving a vessel, though it could hardly be described as an economical method, would be to tow her into position by means of a separate tug. But this method, even though expense were to be disregarded—and expense is the first thing an up-to-date shipowner or his agent thinks about—would be found to be inapplicable in the very case in which assistance is most urgently needed, that is to say, in the case of a large steamer which is of a length nearly sufficient to fill a dock entrance chamber, as in that case room could not be found in the chamber for both the tug and the steamer.

In order to meet this difficulty it has been suggested that a scheme of safe working could be found in granting permission to those in charge of the steamer to work their engines slowly and with extreme caution, to place the tug astern of the ship instead of ahead, and concurrently with the use of the main engines to use the engines of the tug in such manner as to take off any undue way which the vessel might acquire through some mistake in her working. But the records, if they were available (which they are not), would show that the suggestion will not bear the test of experience, and that in such a scheme place must also be found for, and account must be taken of, the possibility of the breakdown of the human machine upon which the working of the scheme depends ; and that cases have occurred in which, owing to error on the part of the men in charge, the superior power of large steamers has mastered the weight and power of heavy and powerful tugs, and the tugs have been dragged with them in their career of destruction.

Regarded as a whole, therefore, it seems to be beyond dispute that an integral part of the machinery with which the entrances and locks of the future should be fitted, some effective means of moving steamers in and out of these entrances and locks must be provided, and that whatever form the mechanical equipment may take, one essential is that means shall be provided by which a vessel with too much way on her can be checked and brought to a standstill outside the entrance or lock, if vessels are to be permitted to approach any such work at times when the gates therein are subjected to a head due to the difference in the levels of the waters above and below the gates. Stated in terms more direct and precise, for no mistake should be made about this, the first provision which is essential for the safety of the working of entrances and locks, is that which can only be made by the construction of leading or guiding jetties, both above and below the locks, alongside of which jetties vessels may be brought up, and from which they can be moved into position in the locks. But such jetties can hardly be ranked amongst the items which are included in the word " machinery," however widely that word may be interpreted.

CHAPTER XIV

THE MERCHANT SHIPPING ACT, 1894; ITS AMENDMENT IN 1900, AND THE CONSEQUENCES THEREOF

THE necessity for the provision of leading jetties in the approaches to locks and other sea gateways, which in the interests of safe working, was insisted upon in the previous chapter, has been recognized in late years in many places, including the Panama Canal, where every steamer which approaches from either end of the locks is brought to rest at a guiding jetty, by which the passage of the vessel is controlled. From the time at which the vessel is berthed at the guiding jetty, movement of the main engines of the steamer is prohibited until the vessel has passed out from the other end of the lock system, whether it be the double-step system at Miraflores, the single-step system at Pedro Miguel, or the three-step system at Gatun.

The interposition of so stringent a regulation naturally involved not only the adoption of more than ordinarily ample dimensions in the plans for the guiding jetties, but the provision of means of a very special sort, by which the safe transport of vessels into and out of each lock could be assured; and the bold step was taken of constructing a rack railway on each side of each pair of locks and of building electric locomotives of special type which might travel on the rack railway in either direction, in accordance with the requirements of the moment, for the purpose of towing vessels through the lengths in which their own engines are not permitted to operate. An experimental engine was first built and tested in actual work; from this engine a type which was considered to be suitable for the intended purpose was evolved, and finally no less than forty engines of the approved type were supplied to the locks at a cost of $13,217 per engine, or over £105,000 in all.

This unique example of electric traction for the purpose of towing line-of-battle ships or great commercial steamers through locks of such unexampled dimensions, is quite in accord with such an environment as that represented by the works on the Isthmian Canal, but must be acknowledged to be beyond the means of those engaged in works of more modest dimensions, and therefore beyond the measure of their possibilities at the present time ; though " the day will come," as the melodramatists say, when power traction of one sort or another will be recognized as a necessary part of lock equipment. But although the details are to a large extent novel, the principle of the towage of vessels through an entrance into a dock by means of a locomotive engine is not new, as the method has been in use for years past in different places. A usual case in which such towage is employed is that of the haulage from time to time of steamers into a graving dock which has been filled with water for their reception, and the gates of which have been opened for the admission of the steamer. Under such circumstances the locomotive engine frequently takes the form of a self-propelling steam crane, probably a ten-ton crane travelling upon ordinary rails with a gauge of 8 feet or thereabouts. The operation has been found to be perfectly feasible, is performed without difficulty, and at a speed which is quite sufficient for the purpose, but which is kept within such limits that the vessel which is being towed can be checked, or can be stopped altogether within a length of a few feet by belaying the stern ropes through which a hold is kept upon the bollards on the sides of the dock during the passage of the ship.

An expedient which has the merit both of simplicity and of economy, and which ensures a reasonable degree of safety, has been adopted in some ports where leading jetties (already referred to as essential for safe working) have been provided. The expedient in practical working usually consists of the erection upon the quays upon each side of the lock, of a series of signposts, of such form and painted in such manner as to render the posts easily discernible in the light of the day, or in the glare of the electric light at night. Each post in the series marks a point either on the inward course of a vessel, or on the outward course, up to which the pilot or master may slowly and with caution order the vessel's engines to be used, but beyond which the engines are by regulation compelled to remain stationary. In this method reliance is placed upon the sufficiency of the length between the signpost and the gates above or below the post, to ensure the possibility of the vessel being stopped even if mistake be made either on the bridge or in the engine room, by means of her own ropes (which should at the time be secured to the bollards on the quay); or if the steamer be of considerable size by a combination of these ropes and of the stern tug by which the stern ropes are being held taut. The method has stood the test of years of work, and if the steamers be not too large, and reasonable care be taken in handling them as they pass in and through the lock, the method may be regarded as efficient; but it is obvious that in such a scheme of working there are always possibilities of regulations being disregarded, and of engines being allowed to revolve beyond the point at which they ought to be stopped altogether. Under such circumstances it is evident that the conditions to which attention has already been called in this manual, and under the stress of which, when alarm has arisen because a steamer may be thought to have too much way upon her, an attempt might possibly be made, in disregard of all rules and laws, to take the way off the vessel by ordering the engines astern, and might again be accompanied or followed by an error in working of such character that the engines would be put ahead instead of astern, and thus the path might once more be opened to the danger of damage and delay.

All steamships—including in that term ships driven by oil or by other form of internal-combustion engines—and many of the larger class of sailing ships are now fitted both forward and aft with power-driven winches. These winches are mainly used for heaving the ships' anchors and hauling them inboard; but the winches have a subsidiary use in that they are employed for warping the ships into or out of docks or berths, at times when tugs are not at hand, or at places where sea room sufficient for the working of tugs is wanting.

This being so there is no valid reason why, if sufficiently substantial bollards be provided on shore, ships should not be warped into and out of entrances or locks, by means of their own power winches. But the operation is not a speedy one and it is useless to shut one's eyes to the fact that neither the shipowners nor the navigators of their ships look favourably or even tolerantly upon such method of working; and having regard to the idiosyncrasies of the men of the sea, hinted at in an earlier chapter, more pressure than can be exerted by dockowners or their engineers must be brought to bear upon the objectors before any reasonable hope can be entertained of persuading or compelling those who are in temporary or permanent charge of steamships, to use the ship's own power and the ship's own ropes for the purpose of warping their vessels into maritime gateways with safety, even if not with undue rapidity.

Hydraulic capstans, which are fixed on the pier heads of entrances and on the round ends of locks, have been provided in many cases in Great Britain for the purpose of assisting vessels in their progress, but it can hardly be claimed that frequent use has been made of the capstans even when no special charge has been imposed for that use. This condition of affairs would undoubtedly be changed altogether if the constituted authorities issued regulations under which the movement of the engines of any steamer would be forbidden after the passage of the steamer beyond certain defined points in the approaches to the locks, as such regulations would leave the captain or pilot in charge no choice beyond using the capstans, or employing his own winches for the purpose of berthing the steamer in the gateway. In either case the desired end would be attained, as safety of navigation would be assured.

Most of the hydraulic capstans which are in use in this country have been designed and constructed at Elswick by Sir W. G. Armstrong, Whitworth and Company, and little or no alteration has been effected in the general type of the capstans since their first introduction many years ago, and but little prospect of development in the designs can be indicated. Two classes of capstan are in use—a direct acting class and a geared class. For moderate powers there is little if anything to choose between the working of the two, but as the makers themselves consider that the practical limit of the pull in a direct acting capstan is about 7 tons, and as this pull is insufficient to move a heavy modern steamer at anything beyond a speed so low as to involve unnecessary loss of time, the geared type must of necessity prevail in the heavier and more powerful capstans of the future.

Figs. 91 and 92 show in section and plan the manner in which an Armstrong capstan of the direct acting type is now constructed, while Figs. 93 and 94 illustrate the method of construction of a geared capstan of moderate size. Figs. 95 and 96 represent a much more powerful capstan, capable of exerting a horizontal pull of 30 tons. It will be observed that both the direct acting and the geared types of capstan are built in such manner that their power and their speeds are rendered variable by different means, and are in inverse ratio to each other. In the direct type the variation is obtained by means of a barrel of two dimensions, the lower part of the barrel being of greatly increased diameter as compared with

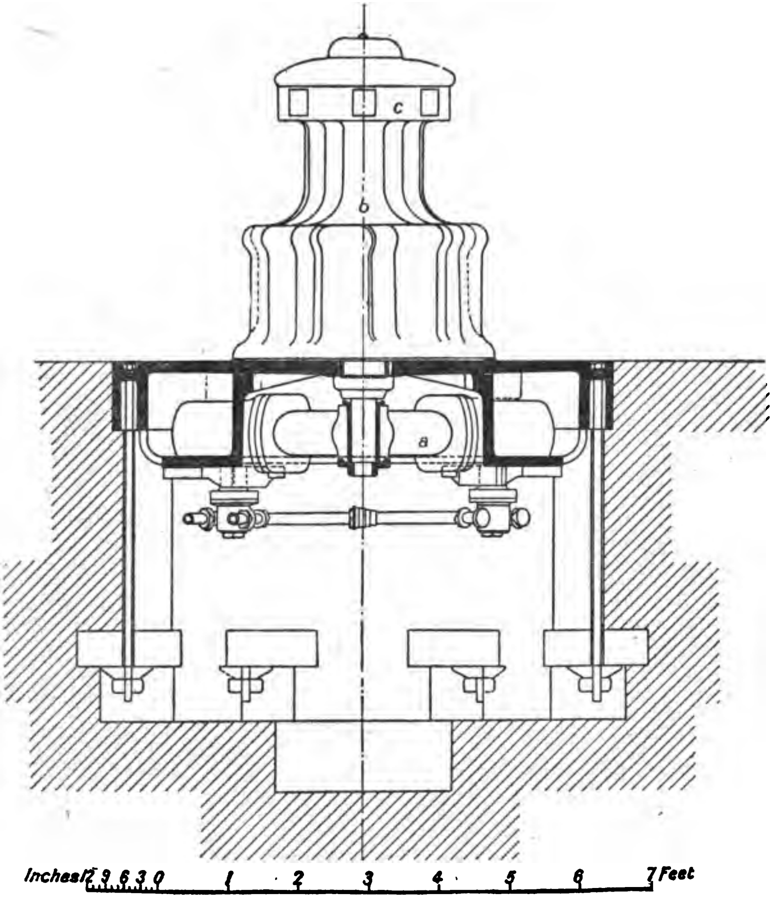


FIG. 91. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Sectional elevation of direct acting capstan.

a Hydraulic engine. *b* Barrel. *c* Head for hand working.

the diameter of the upper part; while in the geared type the variation is provided in the ordinary way by varying the proportions of the gear. It will further be observed that all classes of the Armstrong capstans are furnished with hand gear which is always

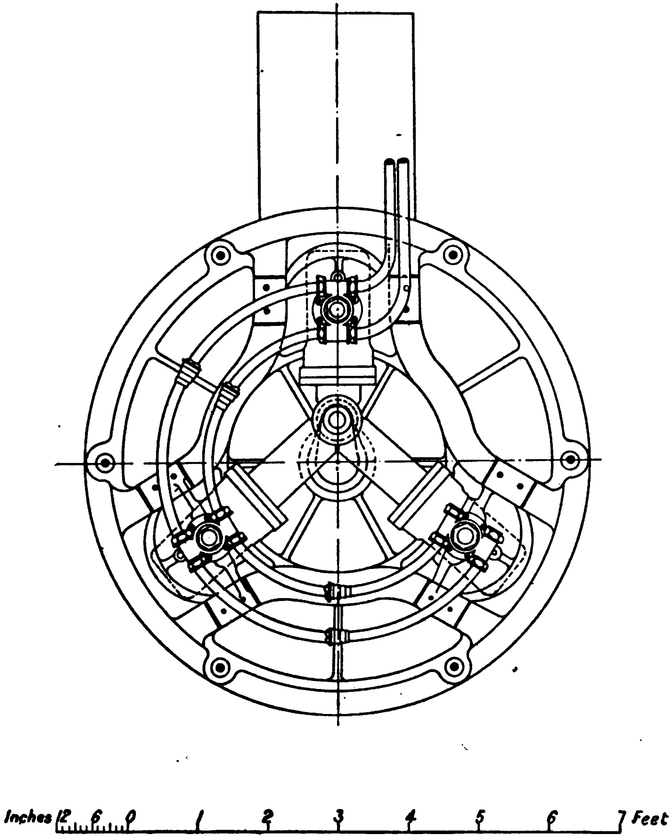


FIG. 92. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Inverted plan of hydraulic engine for direct acting capstan.

available—if an adequate number of men can be obtained—in the event of a breakdown in the hydraulic pumping station, a burst in the main, a stoppage owing to severe frost, or other untoward circumstance.

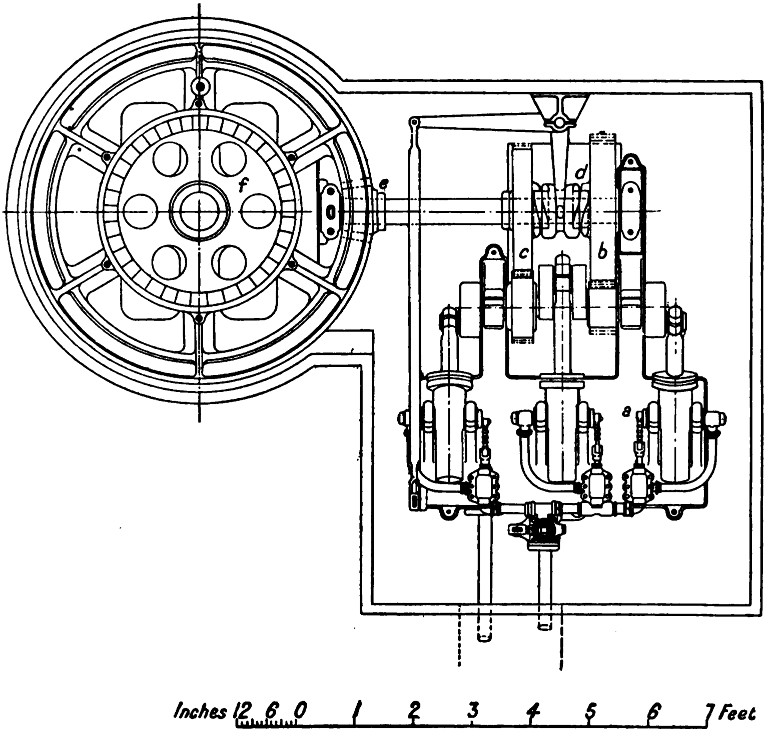


FIG. 93. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Plan of geared capstan, medium size.

a Hydraulic engine. *b* Slow gear. *c* Fast gear.
d Gear clutch. *e* Bevelled pinion. *f* Base of capstan.

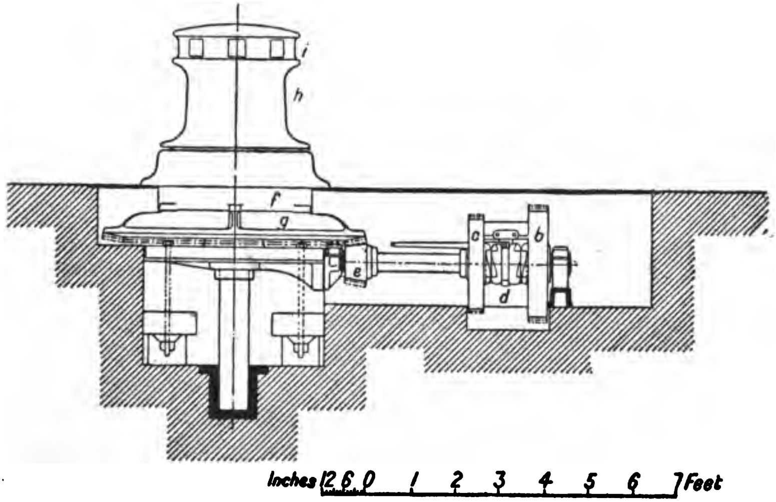


FIG. 94. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Elevation of geared capstan, medium size.

b Slow gear. *c* Fast gear. *d* Gear clutch. *e* Bevelled pinion.
f Base of capstan. *g* Bevelled wheel. *h* Barrel. *i* Head for hand working.

There is no room for anything in the way of advice in a monograph of this sort, even if there were any desire to offer such, but let who will evade difficulties, designers and men in charge of public works cannot escape from them, but must look them in the face, and when questions relating to the proper equipment of engineering structures are raised and when proposals for the supply of the equipment are advanced, serious difficulty is sometimes encountered in the reluctance of authorities who are responsible for the expenditure, to find the money for the equipment. The reluctance is legitimate and must be fairly and reasonably met, especially at times and in cases in which an authority may be desired to spend money on items which appear to be novel and for which the necessity is not obvious.

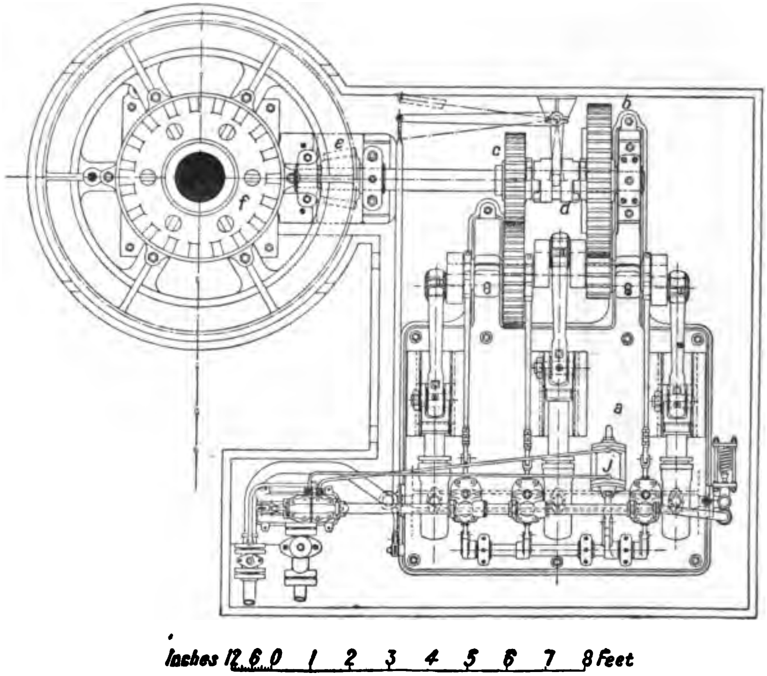


FIG. 95. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Plan of geared capstan, large size.

a Hydraulic engine. *b* Slow gear. *c* Fast gear. *d* Gear clutch.
e Bevelled pinion. *f* Base of capstan. *j* Reversing gear for engine.

The particular case which is in point will even at the present time come under the category described, and may be of more than trifling importance to engineers in many ports and on many navigations. For this reason details will be given in the paragraphs which follow relating to a fact in law which will serve as a corollary to the statements contained in the foregoing pages, and which should serve to influence the minds of such Authorities as those referred to, who in their fiduciary position are clothed with the power of expending public money, or, at any rate, money which belongs to other people and not to themselves. When expenditure of this sort is suggested, the Trustees who are asked to authorize it have, as men of honour and integrity, a natural and proper feeling of jealousy, and it becomes necessary to convince the gentlemen concerned that it is the duty of their Authority to incur any reasonable expenditure which may be required for the provision of machinery which will ensure the safe working of dock entrances, locks, and similar structures on the estate which they administer. In most cases the fact in law referred to will be sufficient for that purpose; the Authority should be made aware of it, and therefore the designer should himself be made acquainted with the history and with the details of the enactment.

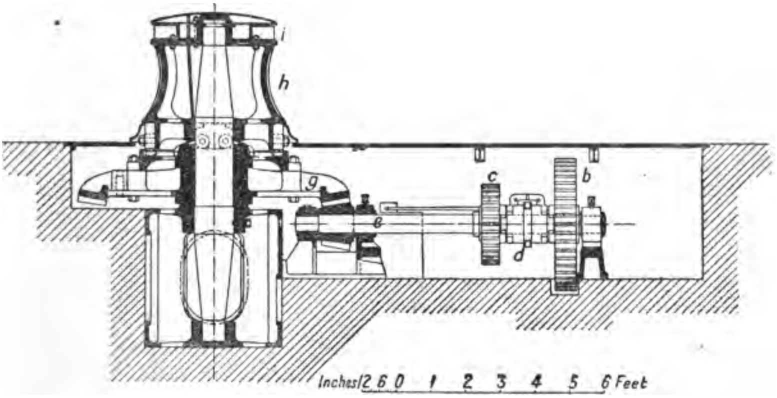


FIG. 96. HYDRAULIC CAPSTAN FOR MOVING VESSELS.

Section of geared capstan, large size.

b Slow gear. *c* Fast gear. *d* Gear clutch. *e* Bevelled pinion.
g Bevelled wheel. *h* Barrel. *i* Head for hand working.

In 1894 the Merchant Shipping Act became a part of the law of this Realm. The Bill for the Act was passed through Parliament under the auspices of a department of the Government of the day, the Board of Trade. This Bill was originally a voluminous measure, but, as is usual, grew much more bulky during its progress through the Houses of Parliament, so that when it received the Royal assent and became an Act of Parliament it contained 748 Sections, and to it twenty-two Schedules were appended. Only two Sections out of this vast number are in point here. The first of these Sections is that numbered 503, the marginal note of which is " Limitation of Owners' liability in certain cases of loss of life, injury, or damage." This note described the contents of the Section with concise accuracy, as the enactment provides that where occurrences take place on board a ship, which involve loss of life or personal injury, and (or) damage to property, without " the actual fault or privity " of the owners of the ship, whether such occurrences take place on board the ship or on board any other ship with which she may get into trouble through improper navigation, the owners of the ship shall only be liable for damages, in the event of loss of life or personal injury having taken place, for an amount equal in the aggregate to £15 per ton of the ship's tonnage, or in the case of damage to property only, for an amount equal to £8 per ton on the same scale. The tonnage in all cases is that which is known as the registered gross tonnage, i.e. that which appears as such in Lloyd's Register, year by year, less a reduction for crew space and for such space only.

The second of the Sections bearing on the point is that numbered 504, which provides that all claims against the owners of the ship may be consolidated into one, and that the damage arrived at in the manner just described, shall cover the sum of all these claims, however numerous the claimants may be.

As will appear as the story proceeds, Section 503 of the Merchant Shipping Act of 1894 proved to be the first step on the way towards the present legal position, which position should, as we have already contended, be kept in remembrance by engineers and designers who have as a part of their functions the duty of expending money on public works, as well as by members of the Authorities which control the expenditure of the money.

The Act of 1894 had not been long in force before the shipowners found a flaw in it, having been stirred up in the matter by certain untoward circumstances which had arisen after the passing of the Act. The flaw seemed to them to impair the efficiency of the Act, as they found themselves still to be liable for the whole of a possible loss of which they thought that a part should be borne by other people, even though the loss was caused by faulty navigation for which their own employees were responsible; and as shipowners are never disposed to sit down in patient forbearance under any burden or charge unless and until they have exhausted every possible effort for the transfer of the burden to other shoulders, they set themselves to compass the amendment of the Merchant Shipping Act of 1894. They put the machinery which is always at their command into motion, they petitioned Parliament, they interviewed the President of the Board of Trade, and as their custom is they succeeded in their efforts. The result was that in the year 1900 the Act which is entitled, " An Act to amend the Merchant Shipping Act, 1894, with respect to the Liability of Shipowners and others," was added to the Statute Book.

This particular amending Act (others had preceded it) presents, so far as dimensions go, a great contrast to the original Act. It contains only five Sections, four out of the five being very short, and has no Schedules.

In the present instance, however, the importance of the Statute cannot be gauged by its size (the whole Act can be purchased for one halfpenny). The content of its Section, of which the marginal note is " Further limitations of liability of Shipowner," is sufficient to prove that proposition, as the Section enacts that the provisions of Section 503 of the Act of 1894 shall extend and apply to all cases, where, owing to improper navigation or management of any ship, that ship shall cause loss or damage to property or rights of any kind, whether on land or in water, whether fixed or movable.

That is the gist of the Amending Act of 1900; it forms the second step in the way to which previous reference has been made, and it means that in the case of a steamer (taken *exempli gratia*) with a registered tonnage of 2000 tons gross, and a crew space of 50 tons, which might collide with and injure any part of the structure or parts of a dock entrance, or of a lock, or of other works of similar character, when no loss of life or personal injury occurs, but when damage is done to property of one sort or another which may extend to a total value of say £50,000, the whole amount which the owners of the estate would be able to obtain from the wrongdoers would be a share of the sum of £15,600, which would be the total amount available for division amongst all claimants for damage, however numerous these claimants might be.

The example is given to illustrate the manner in which the law operates in practice, and these particulars will, it is hoped, make the fact clear that all Authorities who have waterways of any sort under their jurisdiction must reckon with the Act for amending the Merchant Shipping Act of 1894, and particularly with the limitation which the Act contains of the liability of any of the owners of any ship which may damage their property. It cannot be doubted that such a reckoning will be sufficient to incline all reasonable members of Authorities to agree that the expenditure of public money for the purpose of averting the possibility of so serious a loss will be not merely justifiable, but will be a positive duty, as in such case the expenditure upon proper machinery is in the nature of an insurance against loss which in many instances may be serious in extent and far-reaching in effect.

CHAPTER XV

THE POWER FOR THE MACHINERY

In engineering matters generalization is perilous and, as a rule, should be avoided; but notwithstanding the risks which it involves, generalization does sometimes, even when lacking in accuracy, help to clear the ground and to aid a student or a designer to marshal his facts and to arrange his ideas.

Venturing, therefore, on generalization in respect of the power and energy which have been provided for the operation of dock and lock machinery under the stress of modern necessity and amidst the complexities of latter-day life, it may be said that in the United Kingdom and in the British Empire (except in the Dominion of Canada) engineers have for the greater part followed the lead given by Mr. W. G. Armstrong in 1850—when the introduction of the accumulator brought hydraulic power within the reach of almost all Corporations and Authorities, and have adhered to hydraulic machinery—that in Canada and the United States, the electric current is the predominant form of power employed, and that in the Continent of Europe, while both forms of energy are in vogue, it is becoming more and more apparent that electricity has obtained the advantage over hydraulic power and is increasing the distance between the rival form of energy and itself.

It is beyond dispute that considerations which originated in the severity of the winter seasons in the more northerly parts of the United States and in Canada, had a predominant part in the determination of the choice (if, indeed, there was any choice in the matter) made by engineers on the North American Continent between hydraulic power and electric energy for the operation of their dock and lock machinery. They knew that their engineering confrères in Northern Europe were sick of fruitless efforts to save pipes from freezing and cylinders from bursting, at times when the mercury in the thermometer fell and remained at levels far below the freezing-point; that in Russia, Scandinavia, and Denmark it had become the custom to shut down hydraulic machinery as soon as the frost set in, and that this experience had been enough for them. They therefore combined this definite hydraulic disadvantage with the advantages which the electric current admittedly possesses, and plumped for electricity to a man. Others, even in places where winter frosts had no terrors, followed their example; in some cases, as in Panama, because a more or less constant static head of water was available for the production of large quantities of electrical energy at a nominal cost, and in other cases, where the differential head and the quantities of water required for cheap generation of current were wanting, because electrically-driven machines had become the vogue.

In some of the Government Dockyards in England the difficulty of stoppages from frost led to the substitution of compressed air for the distribution of power, but compressed air is far from being an economical medium; the percentage of the power lost in the useless raising of the temperature of the air which is inseparable from the compression, and the excessive leakage which may take place at joints and valves without being discovered, militate against the usefulness of the medium, and as it can hardly be regarded as a serious competitor, it is bootless to discuss it further here.

Latterly "another Richmond" has appeared in the field in the shape of the internal-combustion engine, or more correctly in the multitudinous shapes assumed by that type of motor, and under certain conditions has successfully challenged the older competitors in this mechanical and economical contest, partly because, as has already been suggested, the influence of fashion holds so much sway in the engineering field (and gas, oil, petrol, and other internal-combustion engines are in fashion just now), and partly because under some special circumstances the internal-combustion engine does furnish a convenient prime mover for a gate machine. The intrusion of this type is, however, as yet but an incidental detail, and the true contest still is and for some time will be between the two great methods of distribution, i.e. water under pressure, pumped into pipes of various sorts and sizes, and electric current, generated mechanically and conveyed in varying degrees of tension and density over insulated wires.

Hydraulic engineers understand the first method, by which distribution is effected, as far as it is possible for the human mind to understand the intricate mysteries of any of the processes of nature; electrical engineers understand practically nothing of the second, but that does not matter to them.

There are many branches of engineering practice in which it is necessary when the relative merits of hydraulic and electric distribution and utilization of power are compared, that full weight should be given to the element of flexibility in which electricity has so great an advantage over its rival.

A single example will suffice to make the point clear.

The example will be that of the working of the cargo cranes on the quay of a dock other than a mineral dock. The cranes of an ordinary dock in which general cargo is handled usually have a lifting capacity of from 30 to 40 cwt., while the actual loads lifted will vary from 10 or 12 cwt. to the maximum capacity of the crane. If the cranes be worked by hydraulic power (unless, indeed, they be of double power, a very undesirable complication in a quay crane), whether the remunerative load be 12 cwt. or 40 cwt., the power expended will be the same and the cost will be the same. If, on the other hand, electric energy be employed for the operation of the cranes, the power used and the cost of producing the power will be (if the current expended in overcoming the inertia of and the friction between the working parts be ignored for the moment) practically in direct proportion to the load lifted at each swing.

Machines driven by the electric current undoubtedly have the great advantage of this element of flexibility when working under varying loads. Hydraulic machines have no such advantage and pursue their inflexible way, maintaining uniformity in the power which they consume at each operation, however great the differences between the magnitude of the loads operated upon them may be.

The Institution of Civil Engineers held a Special Convention in 1907 and dealt with many engineering subjects in that Convention. There was a large muster of engineers in the different meetings, many of whom were distinctly representative, were gifted with no small power of speech, and were by no means hampered by either bashfulness or undue modesty. Every member of the Convention had the opportunity of expressing any view which he held on any subject, and of advocating any case which he supported, whether good or bad. Amongst the subjects discussed was one which received considerable attention in the Second Section of the Convention ("Harbours, Docks, and Canals"), and which was entitled, "Dock equipment, including the relative advantages of electric and hydraulic appliances." The subject, therefore, embraced the working of all classes of machinery, not merely machinery for dock entrances and locks. The proceedings of the Convention were published by the Institution in two special volumes, which are at the command of the great majority of engineering students and are well worth the perusal of such. Reference to these volumes will show that the general conclusion arrived at by the experts on both sides, the hydraulic and the electric, whether as authors of the introductory notes on which the discussions were based, or as taking place in these discussions themselves, were: (1) That from the point of view of cost when natural power in the shape of a perennial supply and head of water is not available, and when consequently central stations in which coal must be relied upon for the generation of the power are inevitable, there is little to choose between the two systems so far as cost is concerned, whether it be the cost of original provision, of maintenance, or of working; although, as a matter of fact, more plant is required in an electric station than in an hydraulic station, yet when lighting can be combined with power production in an electric station, the unit cost of the production of the current will be reduced considerably. (2) That for general dock working, in some details of importance, such as questions relating to fire, fire insurance, and the like, the hydraulic system is free from objections inseparable from the use of electric power; on the other hand, liability of leakage from hydraulic mains, valves, etc., leads to possibilities of damage to goods which have no counterpart in electrical systems. (3) That in the operation of dock equipment generally, electrical gear has a distinct claim to superiority which arises out of the flexibility of the power itself, and consequently of the flexibility of the machines driven by it, particularly when the load factor of such machines is very variable.* The fact that this element of flexibility has a great importance in many cases has been already admitted in this chapter, and it was upon it that the most uncompromising advocates of electricity and supporters of electric machinery took their stand. Probably engineers who have had any lengthened practical experience in the working of both classes of machinery will agree with the claim advanced as to the value of this flexibility, *when flexibility is required;* but we are dealing in this manual with power for machinery in dock entrances and in locks only, and whether the machines be employed for opening and closing gates or for lifting sluices or for working capstans for hauling ships into place, it may be safely asserted that in no instance is flexibility required, the load in each case being so nearly uniform that the power required from the machines is all but constant. Consequently, apart from the difficulties attendant upon the use of hydraulic power in severe winter seasons, the advantages for the power to dock and lock machinery must be concluded to lie on the side of the hydraulic machine; so much so that men of experience have urged that even at ports and in harbours where electric machinery alone has been installed, hydraulic machinery should be employed for the working of the locks or entrances, even though such employment might mean the conversion of electric energy into hydraulic power by the utilization of electric current for the driving of hydraulic pumps, and it will be observed that the great majority of the engineers in the Engineering Convention of 1907 who discussed the questions at issue under the subject of dock equipment were explicit in their statements that in their opinion, for gate machines and the like, hydraulic machinery was much to be preferred.

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* See page 187.

In closing the consideration of the arguments which usually arise when the case of hydraulic versus electric power again comes up for judgment, it is unnecessary to do more than recall the general disadvantages which must be confronted in the use of electric energy for power purposes, to which attention was drawn in an earlier part of this work,* and emphasize the fact that these disadvantages are (*a*) general; that is to say, they apply to all classes of electric machines, being due to sensible loss of voltage during transmission from station to machine; and (*b*) particular to dock and lock machinery, as they arise out of the immense difference in the speed of the motor which drives, compared with that of the gate, sluice, or capstan, which is driven, these disadvantages being well known and thoroughly appreciated even by

* See page 50 *et seq.*

those whose practical acquaintance with the working of the machines themselves is yet in an elementary stage.

But there is another consideration to which no reference was made in the Engineering Convention of the Institution of Civil Engineers, and which seems to have been largely, if not entirely, overlooked in the weighing of the merits and demerits of hydraulic and electric power as applied to dock machines or other structures, in which it is of the essence of their *raison d'être* that they are and must be wholly or in part submerged in water for the greater part of their lives; and this factor, though neglected, ought perhaps to have a serious influence in the decision for or against the employment of electric current for the operation of dock and lock machinery, as it is or may be a grave element in the annual cost of maintenance and in the ultimate length of the life of each machine, particularly as the water in which the machines are submerged on the seaboard is always contaminated by metallic salts in solution, and in districts farther inland is frequently impregnated by the pollution due to chemical and other manufacturers' refuse.

Under these circumstances the leakage of electric current from the motors of the machines is conducted through the intermediate connections to the subaqueous portions of the steel, iron, bronze, copper, and other metals of which the sluices and other parts of the machines and of the structures which are operated by them have been built, with the result that electrolytic action is set up. The destructive effects of electrolytic action are now well known, though but little understood, as the havoc wrought in innocent gas pipes and water pipes by ruthless and invading electric tram systems, when these systems were in the insolent period of their first popularity, came within the limits of the horizon and of the recognition of even the man in the street. It seems to be almost, if not quite, certain that much of the destructive injury which has overtaken modern steel-built sluices has been due to electrolysis. Mr. W. C. D. Whetham, F.R.S. (Fellow and Tutor of Trinity College, Cambridge), has described what Faraday called "electrolysis" in the following terms: "When the passage of an electric current through a substance is accompanied by definite chemical changes which are independent of the heating effects of the current, the process is known as electrolysis, and the substance is called electrolyte." What electrolysis means in practice may be gathered from another quotation from the words of a well-known authority (Dr. Fleming, Professor of Electrical Engineering in the University of London), " the general fact is certain that electricity only moves through liquids in association with matter, and simultaneously involves chemical dissociation of molecular groups." That electricity does move through waters containing salts in solution is common knowledge, and the point for the present purpose in Professor Fleming's authoritative statement, is that when the current moves the movement is always associated with that of matter, which means that the electrolytic action leads to the removal of metals from points at which these materials were placed, because they were urgently wanted there for mechanical purposes, to other points where they will be deposited in other forms, where they are not wanted, where their presence will not be beneficial, but seriously prejudicial, to the *régime* of the machines and structures of which they once formed integral parts. It does not require abnormal perspicacity on the part of any student, he need not possess the acumen and the power of deduction which made Mr. Sherlock Holmes' name so famous and his repute so profitable, in order to discern that such a process must spell ruin to the machine, disappointment to its designer, and increase in expenditure to the authority for which it was designed.

This consideration appears not only to be worthy of a place amongst the questions which relate to the use of electric appliances in locks and docks, where vagrant currents which have leaked from these appliances are conducted by metallic conductors and diffused by induction to many parts of submarine machines and structures, and thus intensify the destructive effects of electrolytic action, but to have a just claim to the exercise of influence over designers in their choice of materials for submerged machines. The basis of the claim is that even in situations where the vagrant electric currents are not brought directly to the spot and tempted to pursue therefrom their wayward and mischievous courses, but where the conjunction of steel or iron on the one hand, and brass or copper on the other hand, in saline waters, is sufficient to convert the submerged parts of the machines into feeble voltaic piles, which of themselves serve to generate the currents which, as Dr. Fleming says, will only move through liquids in association with matter, electrolysis will supervene and the same destructive effects will follow although the period required for the destruction will be prolonged.

It is submitted that the questions raised should receive the attention of engineers who are responsible for projects for docks, basins, and waterways, as well as of designers who are or will be engaged in working out the details for the projects of their seniors, and might well engage the interest and stimulate the ambitions of a younger and more ardent circle of engineering life ; for they might be expected to open a vista to engineering students who are yet *in statu pupillari*, and who have the advantage of having within their reach not only the guidance and the direction of the most capable teachers in the engineering world, but who have also access to the unexampled facilities presented by the chemical and mechanical laboratories which are attached to the great modern schools of engineering, in which investigations may be undertaken, and experimental researches pursued, under circumstances, in a manner, and (possibly) with results which will be far out of the reach of those students when they reach the more advanced and, as it may be hoped, more remunerative stages of their career.

APPENDIX

EXTRACTS FROM THE ANNUAL REPORT OF THE GOVERNOR OF THE PANAMA CANAL, FOR THE FISCAL YEAR ENDED JUNE 30TH, 1916.

ELECTROLYSIS AND CORROSION

Cylindrical Valves. Observations during the past year have shown that the corrosive action on the valves has been severe.

In July, 1915, Gatun Locks west chamber was drained and as a part of the maintenance work all of the accessible cylindrical valves were examined. It was found that marked corrosion was taking place on certain parts of the valves, although the entire valve was made of cast iron or steel, no bronze parts being adapted in the original design. It was found that in the lower level an average of 75 per cent of the seal segment nuts were corroded and an average of 106 per valve were required to replace those in bad condition. In some cases fully half the nut had disappeared. The original nuts were made of steel, but, for the purposes of test, valve No. 502 was installed with ten brass nuts on one seal segment, ten refined iron nuts being installed on another segment. It was also found that the bolts holding the valve stops in place were in such a condition that they had to be replaced in every valve in the lower level. In valves Nos. 503–506 brass bolts 1 inch by 3½ inches were used in place of the steel ones taken out.

Similar conditions were found in the east chamber at Gatun when it was drained on September 16, 1915, in every case the corrosion being excessive in the lower level and gradually decreasing toward the Gatun Lake level. All valves were put into good condition and painted with red lead.

At the Pacific Locks no examination has been made of the valves at Pedro Miguel or of those on the west side of Miraflores centre wall. The east valves at Miraflores were found to be in fair condition. On February 24, 1915, cylinder valve No. 716 at Miraflores upper level was dismantled with a view of ascertaining the condition of the valve and stem and the tube for the valve stem in order to determine on the protective measures necessary.

The main part of the valve stem, consisting of three 16 feet 6 inch lengths of extra strong galvanized pipe, was in first-class condition, no sign of corrosion being apparent. The only sign of corrosion on any part of the stem was a $\frac{1}{8}$ inch pitting which had occurred on the forged steel end of the valve stem. It was unnecessary to dismantle any of the other valves, as all parts requiring protection from corrosion could be reached without the necessity of going to this extreme.

Inasmuch as all painted surfaces of the valve had failed, it was decided to coat all exposed iron and steel surfaces with enamel.

Rising stem valves. All submerged iron and steel work of the rising stem valves have been submerged practically continuously since the locks were first watered on the following dates :

Gatun, east chamber, first watered January 3, 1914.

Gatun, west chamber, first watered September 23, 1913.

Miraflores, east chamber, first watered January 12, 1914.

The condition of the valves at Pedro Miguel has not been examined as yet.

The following is a detailed description of the condition of the various parts of the valves as found at the time the culverts were unwatered :—

At both the Atlantic and Pacific locks there was considerable corrosion of the valves. The $\frac{1}{2}$-inch plates have been attacked in a manner similar to that of the lock gates. In certain cases, such as the lower valves at Gatun, together with the upper and lower valves at Miraflores, they have been violently attacked on all rivets. Out of sixty-four rivets on one butt-strap, sixty-two were practically eaten away and the remaining two were loose. It is also to be noted that the rivets outside the surface receiving the full static head on the valve are practically free from attack.

The bottom seal casting of the valve which comes in contact with the babbitt metal seal on the bottom of the valve is being rapidly eaten away, in many places the pitting being over three-sixteenths of an inch deep. A number of valves at the Pacific locks were in such condition that the bottom seal had to be machined off in order to make the valve tight. In order to protect the valve from any further electrolytic action between the cast steel seal and the lower babbitt metal seal, all babbitt metal has been removed and replaced with a seal of greenheart lumber.

Side seals of valves. Some of the bronze side seals and springs were found to be broken, both at Miraflores and Gatun. A number of the bolts on side seals at both Gatun and Miraflores were found broken. With the above exceptions the seals were in good condition and only required a small amount of draw filing to make the contact surfaces perfect.

Top gate seal. The top gate valve seal is of cast steel and is held in place by bronze bolts.

The worst cases of corrosion are at the upper and lower valves of all locks. In practically every instance the corrosion has been excessive around the heads of the bronze bolts, cutting away the metal and in some cases allowing the bolts to loosen and fall out. Several castings had to be replaced, although in every case the rubber seal was still soft, pliable, and could have been retained in service. The worst case of corrosion of the seal occurred on the upper valves at Miraflores.

Piers and side seals. At Gatun practically all valves were installed with fixed side seal castings, which all gave evidence of considerable corrosion, but not sufficient to cause any leaks.

At Miraflores removable side seal strips were of machinery steel and in every case corrosion had reached such a point that all side seals had to be replaced. Inasmuch as the corrosion had apparently been aided by the proximity of the bronze side seals which bear upon them, it was decided to replace all machinery steel with lignum-vitæ wood, in this way tending to place an insulating substance in contact with the bronze. All porous concrete around the fixed irons was removed and replaced with cement, and wherever babbitt metal had been used to fill the recessed holes for boltheads at the Pacific locks the metal was removed and replaced with cement.

Roller Trains. At both the Pacific and Atlantic locks there was considerable corrosion of the roller trains, the rollers of which are made of tool steel. At the Atlantic locks a number of rollers, bolts, and filler castings were found missing. All were replaced and the heads of all bolts were riveted over to prevent future losses.

At the Pacific locks similar conditions were found, and as it is impossible to protect the rollers by any paint, arrangements have been made to instal ½-inch pipes from the tunnel floors down to the base of the roller-train tracks. Crude oil will be forced through the pipes, and it is believed, from results of experiments made with a model, that the crude oil will rise along the surface of the roller-train track and in this way protect the rollers by coating them with oil.

Conclusions. As a result of the examination of the valves at Gatun it was decided to have them coated with bitumastic enamel, although the fixed irons and roller trains were simply painted as a protection against electrolytic action. At the Pacific locks the experience obtained at the Atlantic end enabled more complete protective measures to be taken, the following being an outline of the work done :—

1. All bronze side seals were lined up and strips of zinc bolted to the valve each side of the seals at the bottom of the valve.

2. Where necessary, the bottom valve seal was machined off to give solid metal contact with the bottom seal.

3. All removable side seal strips were taken out and replaced with lignum-vitæ wood strips. Where removable strips were not installed the fixed irons were milled down to take the wooden side seals.

4. All babbitt metal used in the assembly of the valve for embedding and protecting boltheads from corrosion and for calking purposes was removed and replaced with cement.

5. All babbitt metal used in the bottom seal was removed and replaced with greenheart lumber.

6. All steelwork of the valve was coated with bitumastic enamel. This left only the bronze side seals exposed.

7. All fixed irons were coated with bitumastic enamel.

8. The channel iron supports for the rollers were coated with bitumastic enamel, and arrangements made to lubricate the roller trains and tracks with crude oil during operation and while the valves are submerged.

9. All submerged portions of the valve stems were coated with bitumastic enamel.

10. All bronze bolts are being replaced with steel as fast as breakage occurs.

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